Slow The Smoke Project

Summary Report

Public participation project on domestic solid fuel burning and air pollution in Bristol

BRISTOL CITY COUNCIL

KWMC
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Acknowledgements

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1 Introduction

Air pollution can harm humans, animals, plants, and ecosystems, and corrode materials, buildings and cultural heritage sites. The World Health Organisation (WHO), European Union (EU) and the United Kingdom (UK) have health-based thresholds in place for various pollutants of concern including Nitrogen Dioxide (NO_2) and Particulate Matter (particles with a diameter of less than 10 and 2.5 micrometres – PM_{10} and $PM_{2.5}$). In the UK, a 2016 study by the Royal College of Physicians and the Royal College of Paediatrics and Child Health, estimated approximately 40,000 premature deaths are attributable to exposure to outdoor air pollution each year[1]. In 2017, Bristol City Council commissioned a report to investigate the health impacts of air pollution. It concluded that that exposure to both Nitrogen Dioxide and Particulate Matter contributed to approximately 300 deaths each year in the City of Bristol, which equates to 8.5% of deaths in the City of Bristol being attributable to air pollution[2].

Air quality in Bristol and the impact of solid fuel burning

In Bristol, NO_2 and PM_{10} / $PM_{2.5}$ are the pollutants of primary concern. Bristol City Council has been monitoring and evaluating air pollution in the city administrative area since the late 1990s. The Council currently has seven continuous analysers and >180 passive diffusion tubes measuring NO_2 and there are three continuous analysers in Bristol measuring PM_{10}/$PM_{2.5}$. Data from these monitoring stations can be viewed on the Open Data Bristol platform and a summary of the data and a review of the status of air pollution in Bristol is available in the Council's Air Quality Annual Status Reports. While air pollution can come from several sources, the main sources of concern within the Bristol urban area include transport, domestic solid fuel burning and industry.

The use of solid fuel for heating presents an important source of indoor as well as outdoor air pollution. The Department for Environment, Food & Rural Affairs (DEFRA) 2020 national estimates that domestic combustion from indoor appliances contributed 15% of all primary PM_{10} emissions and 25% of all primary $PM_{2.5}$ emissions. Wood as a fuel contributed 17% of all primary $PM_{2.5}$ emissions. From 2010 to 2020, the relative proportion of national $PM_{2.5}$ emissions from domestic wood burning increased by 35%.[3 4 5]. In 2020, Bristol City Council commissioned a report to explore the impacts of solid fuel burning in Bristol[6]. The report used two different methodologies to estimate emissions from combustion of wood and coal. The report found that wood burning contributed to 241-791 tonnes of PM_{10} and 235-772 tonnes of $PM_{2.5}$ and coal burning contributed to 20-22 tonnes of PM_{10} and $PM_{2.5}$ each in 2014. The report also indicated that there is a growth in the numbers of HETAS (Heating Equipment and Testing Approval Scheme) registered wood burning installations in Bristol (120 in 2007 to 901 in 2017). A 2022 press release by the Stove Heating Alliance reported a 40% increase in sales of wood burning stoves compared to 2021 which they linked to consumers acting due to an increase in energy bills[7].

[1] https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution
[2] https://www.bristol.gov.uk/documents/20182/32675/Health+Impacts+of+Air+Pollution+in+Bristol+February+2017.pdf/4df2fce5-e2fc-4c22-b5c7-5e7a5ae56701?t=1489411469000
[3] Emden J and Murphy L. Lethal but legal: air pollution from domestic burning. London: Institute for Public Policy Research (IPPR); 2018. [Accessed 13 September 2022]. Available from: https://www.ippr.org/research/publications/lethal-but-legal
[4] Department for Environment, Food & Rural Affairs (Defra). Emissions of air pollutants in the UK – Particulate matter (PM10 and PM2.5). Updated 18 February 2022. [Accessed 11 July 2022]. Available from: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25
[5] Chief Medical Officer's Annual Report 2022: Air Pollution - https://www.gov.uk/government/publications/chief-medical-officers-annual-report-2022-air-pollution
[6] https://www.bristol.gov.uk/files/documents/582-bristol-solid-fuel-burning-j4041-report/file
[7] https://stoveindustryalliance.com/increase-in-wood-burning-stove-sales-points-to-consumers-taking-action-to-tackle-heating-bills/

Local and national policies related to domestic solid fuel burning

Current evidence suggests that there is no safe threshold for exposure to $PM_{2.5}$ and domestic solid fuel burning is a notable contributor. As such domestic sources, especially domestic solid fuel burning is a major concern in Bristol and many urban areas across the UK. The recent change in citizen behaviour and growth in the number of domestic solid fuel burning appliances have exposed the failure of smoke control legislation to control air pollution from domestic sources, meaning that a more effective solution is needed. The UK Government updated its Clean Air Strategy[8] in 2019 and sets out plans for dealing with all sources of air pollution. The Strategy has a dedicated section on actions to reduce emissions at home (page 57). Options to reduce the impact of domestic solid fuel burning include:

- New powers for local authorities related to raising awareness of Smoke Control Areas and enforcing these areas.
- Ensuring only the very cleanest stoves can be bought and installed through Eco-design regulations.
- Ensuring only the cleanest fuels are available through regulation of the sale of unseasoned or wet wood (which is the highest polluting when burned).
- Voluntary industry initiatives such as Woodsure ' Ready to Burn' Scheme and Stove Industry Alliance Eco-design Ready brand.

Bristol City Council is assessing policy options to tackle local sources of particulate matter. Bristol City Council does not have an Air Quality Action Plan in place for $PM_{2.5}$ but there is an aspiration to meet WHO interim target 4 levels by 2030 in Bristol's One City Plan. Alongside developing the clean air compliance measures for NO_2, the issue of PM pollution has continued to be considered. The whole of Bristol is a smoke control area, however, enforcement is currently difficult and there is limited understanding of the way in which people use solid fuels in the city in terms of types of fuel, appliance and frequency of use.

[8] https://www.gov.uk/government/publications/clean-air-strategy-2019

2 Overview of Slow the Smoke

The project aim was to achieve air quality benefits in both the short and long term through the planned monitoring, engagement and awareness raising activities in a pilot area of the city (Ashley Ward which includes the areas of St Werburghs, St Pauls, Ashley, and Montpelier). If successful, the project template could be rolled out more widely in Bristol and recommendations provided for other local authorities to learn from the Bristol experience.

The Government's 2019 Clean Air Strategy highlights that the use of solid fuel has increased in popularity in recent years and that the health evidence shows that significant harm can occur to health due to emissions from solid fuel. This project aligns with the aim of the Clean Air Strategy to reduce the emissions from domestic wood and coal burning appliances. It achieves this through the innovative integration of reference monitoring, citizen science monitoring and several citizen-led engagement activities.

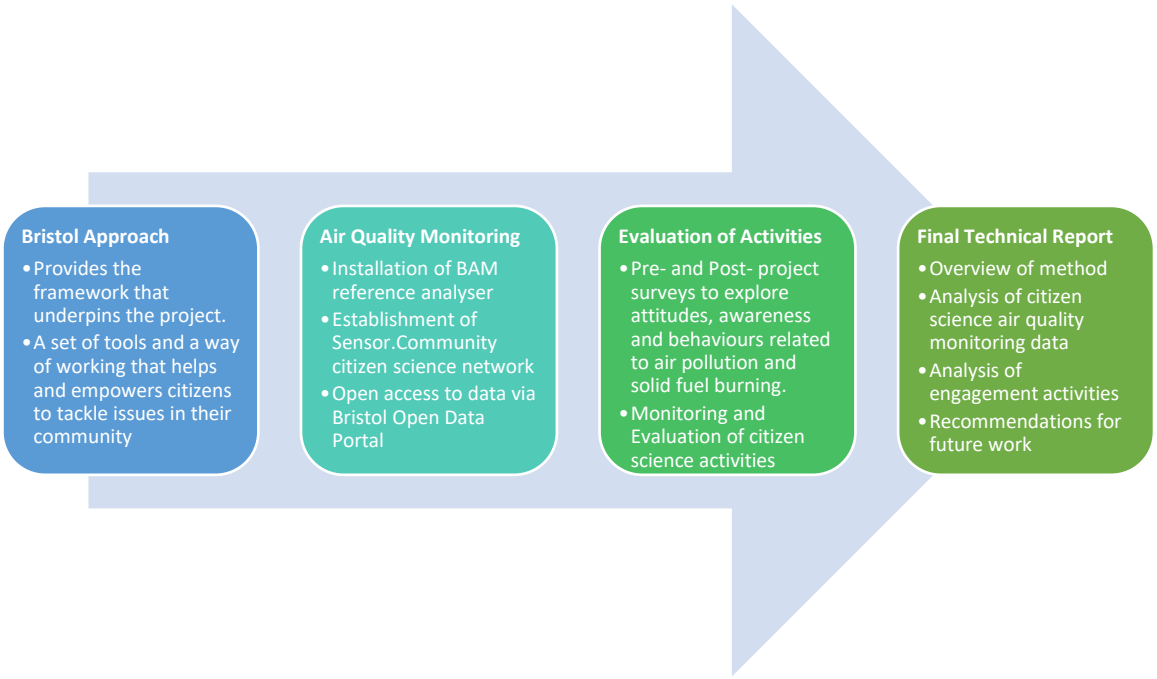


Figure 1: Schematic of the Slow the Smoke approach

The principles of the Slow the Smoke project are based on the established but innovative citizen led engagement process, the Bristol Approach (Figure 1 and Figure 2). The Bristol Approach is a set of tools and a way of working with citizens that helps and empowers different groups to tackle issues in their community. It comprises of a 6-Step Framework, which supports the gathering of information and experiences, clarifies community and individual values, and creatively explores outcomes and solutions.

Figure 2: Schematic of the Bristol Approach

Introduction to the St Werburghs / Ashley Ward pilot area

The pilot area within the city was identified through the evaluation of HETAS installation data at Low Super Output Area (LSOA) level which indicated where rates of solid fuel use are at their highest, relative to other wards within the city. Figure 3 below shows the locations of solid fuel installations (stoves and flues for example) registered by HETAS and plotted at LSOA level.

It is important to note that the Ashley Ward comprises of many different socio- economic and cultural groups. As it is with many areas of Bristol, the neighbourhood has strong identities. The St. Paul's area has a strong heritage to the Windrush generation from the Caribbean community. The neighbourhood also has a strong heritage of social change and activism with the Bristol Bus Boycott in 1963. According to St. Paul's residents, the St. Paul's neighbourhood is in a state of change, with property prices rising, and many new people moving into the area with no connections to this heritage. At the same time, the area also has a large Somali community and residents from Black African heritage. Geographically the neighbourhood is situated next to the M32 motorway and falls directly outside the boundaries of the Bristol Clean Air Zone introduced in the city by Bristol City Council in November 2022. This neighbourhood does not have a high number of wood burners installed, but still falls within the LSOA, Ashley Ward.

The M32 motorway also forms one of the boundaries of St. Werburghs neighbourhood. The neighbourhood has a mix of social and private homes. There are trainlines in the area and main roads feeding traffic into St. Paul's and the city. The area has a history of van dwellers and there are still a few people who live in vans. One of the defining characteristics of the area is the community led self-build housing estate called The Yard, which was built with visions of being sustainable: environmentally, socially and economically. This area has a high concentration of wood burners installed. Montpelier is perceived as a community with areas of a higher socio-economic status, but you also find van dwellers in the area. Together with Ashley they have high concentration of wood burners installed.

"St. Werburghs is an interesting area, you have many people staying in vans and burning fuel to stay warm, but there are also a lot of affluent people in this area who are using woodburning as a lifestyle choice."

Carla, Citizen Scientist St. Werburghs

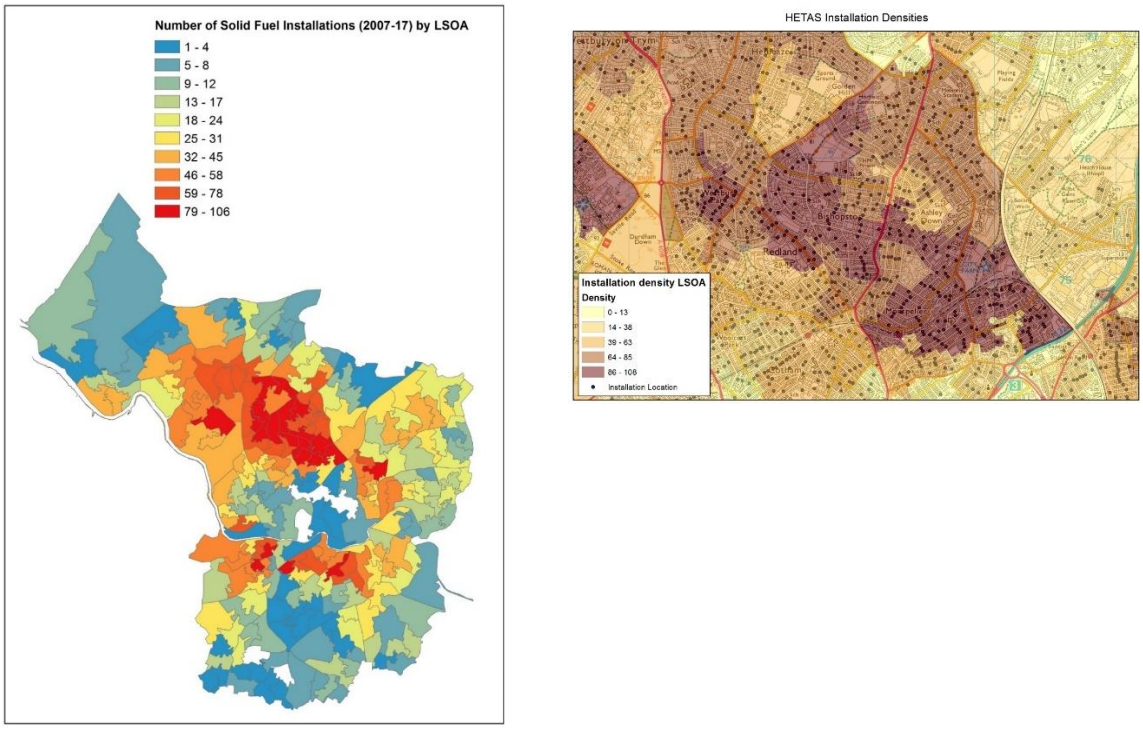


Figure 3: HETAS registered installations in Bristol and in the vicinity of Ashley Ward

According to the Ashley Ward profile for September 2022, the Ashley Ward has a total of 33.5% of residents from Black, Asian or other Minority Ethnic groups. The statistics also show 23.8% of the residents were born outside of the UK.

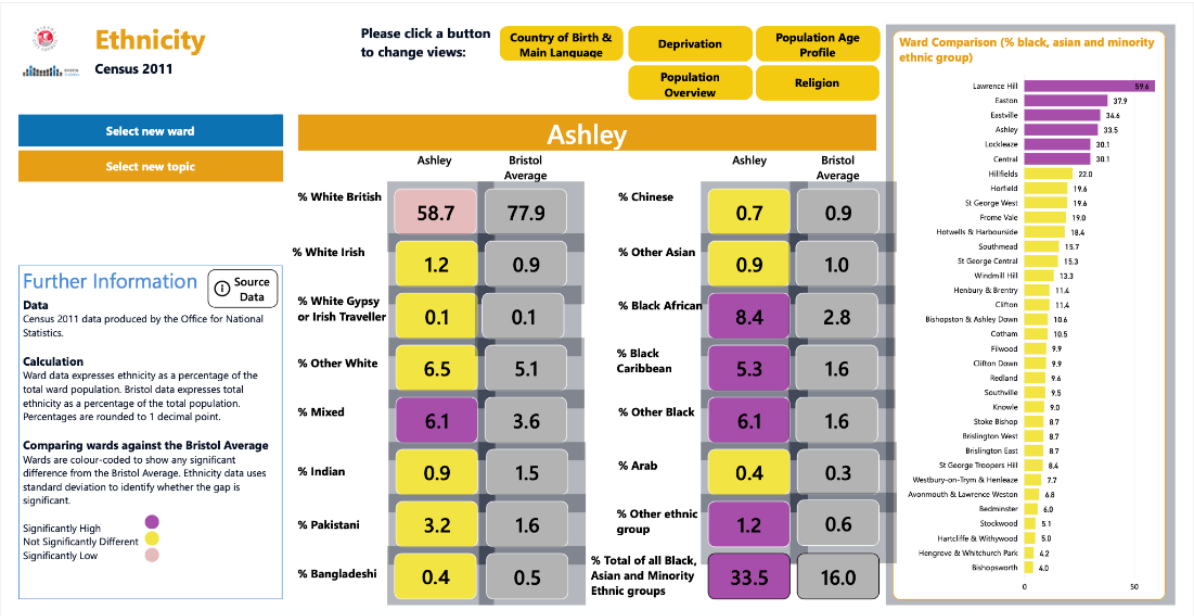


Figure 4: Ethnicity profile for Ashley Ward from the Bristol City Council Ward Profile Report for 2022.

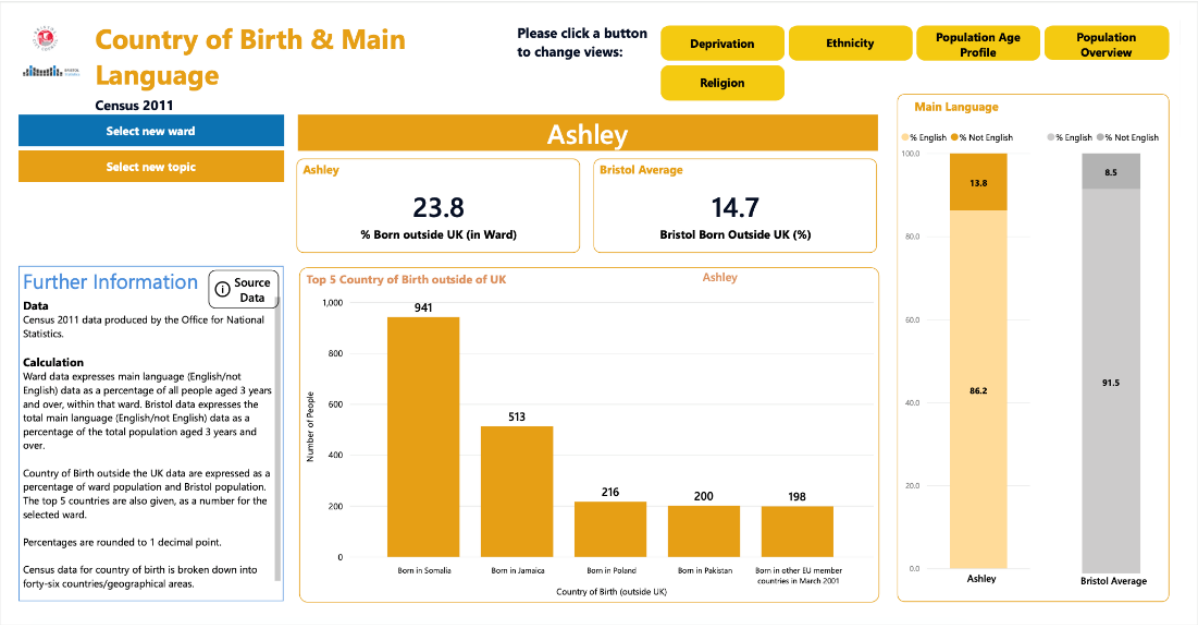


Figure 5: Country of birth and main language profile for Ashley Ward from the Bristol City Council Ward Profile Report for 2022.

3 Public engagement activities

This section includes a summary of the approach taken in developing the citizen science and public engagement activities and an evaluation of the citizen experience. The activities in this section were primarily led by KWMC.

Recruitment of citizens

The recruitment activities for citizen scientists included social media posts and personal emails to organisations in the area. We also published an article in the local community magazine, Vocalise, in the Autumn 2021 to recruit participants, particularly citizen scientists and to introduce the project to the community. A recruitment survey which was sent to the neighbourhood in Sept/Oct 2021 captured the details of 142 citizens who declared an interest to be involved in the project, either as citizen scientists, workshop attendees or to be informed about the findings. Many of these people subsequently registered onto the project workshops, either as citizen scientists or attendees over the course of the project. In October 2021, KWMC successfully recruited 10 residents from the Ashley Ward area, including Montpelier, St Paul's and St Werburgh's. The locations can be found on Figure 6 below.

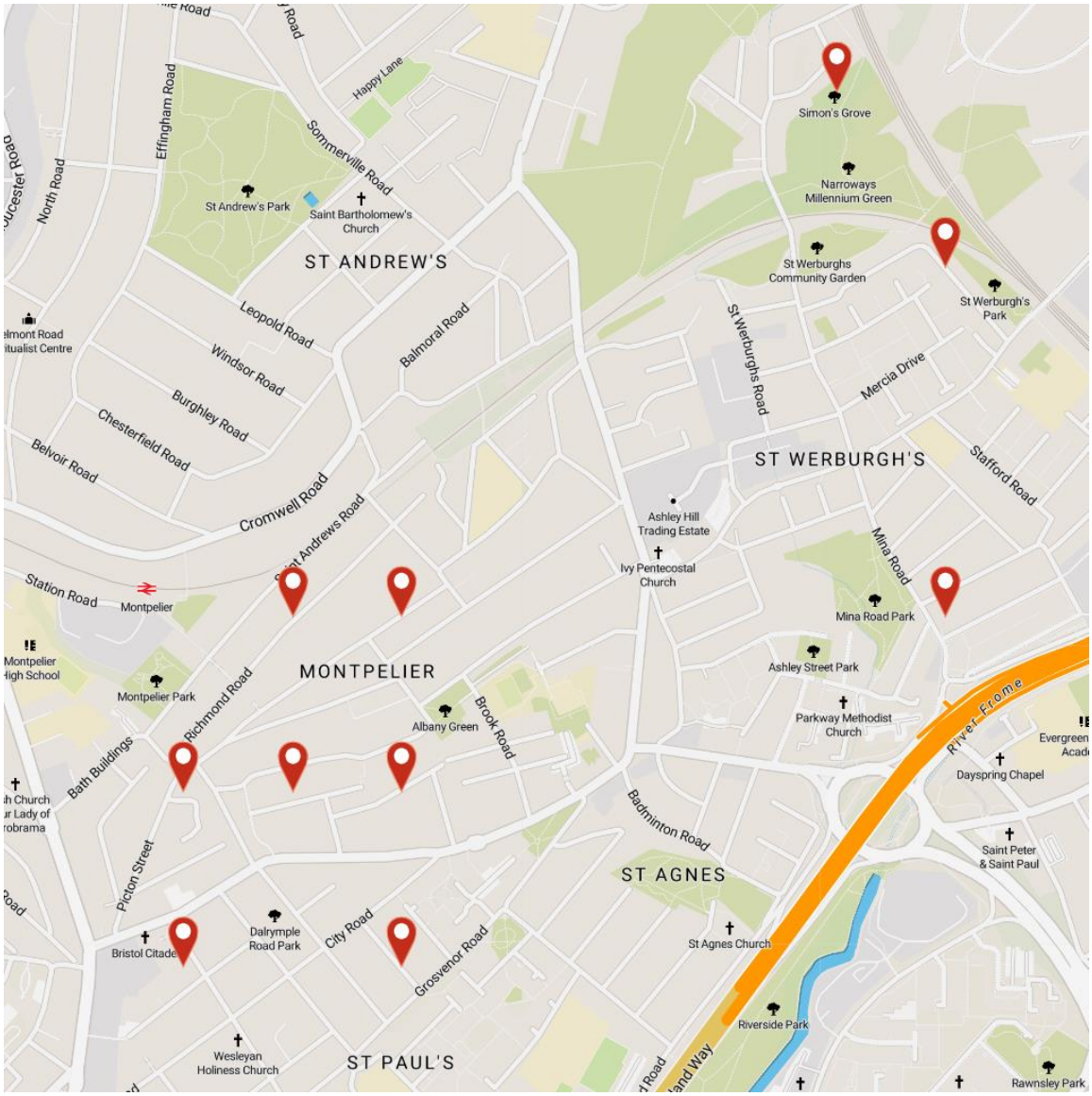


Figure 6: Sensor Community map of sensors installed in Ashley Ward, Montpelier and St Werburghs

Most citizens who participate in citizen science are well educated[9] and finding ways of engaging less educated or less privileged participants is an important goal if citizen science genuinely wants to move towards involving everybody. As part of the Bristol Approach, it is important that equality, diversity and inclusion principles are considered within the recruitment processes to ensure the communities within which the methodology is applied are represented.

The Slow the Smoke citizen scientists consisted of three women and seven men, with one resident from a BME background. The project tried to be as inclusive as possible in our recruitment, by sharing the opportunity with the wide range of BME organisations, and housing organisations who operate in the area. Most of the citizens were recruited via social media, with one via email and one via the local community magazine. Having a low BME representation of the community as our citizen scientists, the project tried to address this imbalance during the planned engagement events and workshops with the wider community over the duration of the project.

People had many different motivations for getting involved. Some had new families and wanted to get a better understanding of what air quality was like where they lived; some had concerns about the impact of road traffic and congestion where they lived and affecting the air quality on their commutes to work and school; some had wood burners installed and were hoping to get better information about the health impacts of these, or when and if they were ok to use.

Ensuring the activities were accessible

Accessibility for participants is an important part of the project design. Taking into consideration the diversity of the community in St Paul's, where a large proportion of people don't speak English as a first language, having translators for activities was important. For example, during the family workshop in St. Paul's, the Play Wooden team were able to support with Somali translation. Accessibility was also considered when booking venues and when sending invitations, to inquire whether people have access or dietary needs. However, sometimes, as is the nature of community events, people just turn up, so there were some unexpected situations. For example:

- During the family workshop at St. Paul's, a wheelchair user joined who was only able to access the outside area of the venue. To facilitate this individual, the facilitator moved one of the activity groups outside.
- A participant asked for a prayer room, which was accommodated by the venue who had spare rooms available.
- For family workshops, parents needed to respond to children's needs, which required flexibility in delivery of the workshop. Working with a childcare provider during the sessions supported people with childcare.
- A participant who was hard of hearing joined a workshop that involved a performance and discussion.

Maintenance of the Sensor.Community Sensors and citizen science community

A challenge for Bristol City Council and KWMC was to ensure that the Sensor.Community sensor devices collect data consistently. Sensor.Community (the open data platform for the particulate sensor data) would send automated notifications when sensors are not collecting data (see Section 5 for details on the sensor). Notifications received by KWMC were redirected to participants to identify the issues for the sensors not receiving data. Issues include wifi issues like password changes or outages or simple things like a device being unplugged. To further empower citizens, KWMC set up an automated redirect to the individual sensor ID holder, with a document to support them to problem solve the issue. The citizens reported that this worked well with them and that they had enough support to be able to address the problem. It also freed up resources for KWMC.

[9] Haklay, M. (2018). Participatory Citizen Science. In: Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J. & Bonn, A. (Eds), Citizen Science: Innovation in Open Science, Society and Policy. London: UCL Press. https://doi.org/10.14324/111.9781787352339

Of the 10 citizen scientists who originally installed the sensors, one moved out of town, but the project was able to locate the sensor in a similar location with the landlord of the property. This meant that the sensor could still contribute to the study but there was not the same contribution or enthusiasm from the new participant as there was from original citizen scientist. Another citizen scientist also dropped out of the study.

The ongoing engagement with the citizen scientists included a data diary for participants to complete. They were prompted, via an email, to input any events they noticed, which might provide a narrative to the data from the sensors and subsequently providing context and humanising the data. Table 1 provides a sample of interesting events which were documented during the month of January 2022. Upon analysis of the data from the sensors, there were no events recorded on the individual sensors, but they showed a general picture of poorer air quality during this cold month, which supported the events the citizen scientists noticed.

The data diaries were valuable to support a picture of the air quality data, it also supported the citizen scientists to take notice of what was happening around them. Feedback received was that an App would be helpful to have on their smartphone, as they forgot to make entries when they returned home, they also asked for suggestions on specific things to take notice of when they were outside.

Table 1: Sample of citizen scientist data diary inputs

Date	Citizen ID	Observations			Action taken
		Met	Sensory	Activity	
21/01/2022	Colin: 66966	Freezing	Acrid choking diesel fumes in the street.	A couple of van owners had just got their vehicles defrosted on very cold still morning	I got out of the street ASAP. Very unusual to notice impact on breathing - slightly fearful. I now understand why people in heavy traffic areas complain so much about fumes and also why it's time we banned older diesels altogether.
26/01/2022	Ruth: 66979	Cold	Very smelly with car fumes.	Cars, 8:30 am as I'm walking to work.	We have lit our fire a bit over this month, and I have been looking out for woodsmoke to report, but haven't noticed any, however yesterday when my boyfriend came home from climbing around the corner at around 8pm he came in smelling of woodsmoke.

Summary of the citizen science and public engagement workshops

Alongside the three workshops with citizen scientists, KWMC also hosted five workshops within the wider community of the Ashley ward over the duration of 2022. The workshops and attendance are described in Table 2. Before the first workshop, KWMC had a brainstorm session with two citizen scientists, who are active St. Paul's residents: Oluwa, director of a social enterprise Play Wooden CIC, also serves as a board member for Malcolm X Community Centre and Helmut, a parent and keen cyclist, who has lived in St Paul's for several years[10]. The outcomes from these meetings helped to inform the content of some of the workshops and ensure that the project followed the co-design principle of working with citizens and make their part of the decision-making process.

Table 2: Workshops dates, title, audiences, and attendance

Workshop	Date	Title	Audience	Attendance
Workshop 1	19/10/21	Build your own sensor workshop	Citizen Scientists	6 adults
Workshop 2	23/10/21	Build your own sensor workshop	Citizen Scientists	4 adults
Workshop 3	16/03/22	Making sense of data online workshop	Citizen Scientists	7 adults
Workshop 4	14/05/22	Play data with Play Wooden CIC at Malcolm X Centre	Inner City Families in St Pauls	20 adults 17 children
Workshop 5	09/07/22	How do we tackle air pollution in St Pauls?	Wider community in St Pauls / St Werburgh's, including others outside of the ward.	10 adults 4 children
Workshop 6	08/10/22	Sound the Air – a Data Sonification and recording workshop	St Paul's Community	17 adults 8 children
Workshop 7	19/10/22	Explore Air Pollution in Minecraft with young people at Docklands Youth Centre.	Young People in St. Paul's	9 young people 4 youth workers
Workshop 8	05/11/22	A showcase of citizen science, data, community voices and art.	Community in Ashley ward and other interested parties in air quality.	16 adults 8 children
Total				80 adults 45 children

[10] **PLEASE NOTE**: as part of the project ethics and data protections process, all participants were asked for permission to use their names or identifying features (e.g. pictures) for reporting purposes. If the participant is named, then this indicates that permission was received. Any evidence attributed to an anonymous source indicates that no-permission was received. KWMC coordinated this process.

KWMC evaluated the workshops using forms which anonymously captured equality and diversity information (Table 3). Typically, citizen science activities are dominated by white, middle class, middle-aged men, so it was encouraging to see a diversity of cultural heritage represented at the workshops and to see a larger female than male presence.

Table 3: Cultural, disability and gender data of workshops participants

Cultural Heritage	Disability	Gender
		
Prefer not to say White Not sure Black or Black British Multi heritage Asian or Asian British	No Yes Prefer not to say	Female Male Prefer not to say

Workshops 1 and 2: Onboarding citizen scientists

KWMC held two workshops with attendees, one on a weekday evening and another on a Saturday to accommodate people's lifestyles. People were informed about how their data will be used for the project and supported to build their own DIY low-cost particulate sensors (i.e. Sensor. Community Sensor). Guidelines on how to build, register and install the sensors were provided. These workshops also had the additional benefit of bringing the citizen scientists together to build a community of users and a common purpose for the project. It also allowed the project team and citizen scientists to meet and to answer any technical, scientific or non-technical questions in a comfortable space. After the sensors were built, KWMC staff arranged visits with the Citizen Scientists to help install and connect to the devices at their homes.

Figure 7: Pictures from the sensor building workshops in October 2021

Figure 8: Sensor guides used for sensor building workshops in October 2021

Workshop 3: Making Sense of Data Workshop for Citizen Scientists

On 16 March 2022, KWMC and Bristol City Council hosted an online workshop for citizen scientists to make sense of data collected over the winter period. Steve Crawshaw (Air Quality Project Manager at Bristol City Council) facilitated this, using the Bristol City Council Open Data Platform. Seven of the ten citizen scientists attend the workshop, with one of them not able to participate after experiencing technical difficulties. To prioritise the content for the participants, we compiled a questionnaire to support us to design the workshop. The three main topics people were interested in were:

- How do I analyse the data from my own sensor?
- How can we use the data to inform policy and put pressure on Bristol City Council to take a harder stance on the issue of air pollution?
- How do I share the data from my sensor with others in a meaningful way?

Steve Crawshaw created a screen recording as a walk through to introduce people to the Bristol City Council Open Data Platform[11]. During the workshops participants got an overview of air pollution, including the sources, impact on health of NO_2, PM_{10} and $PM_{2.5}$. They were shown what the air was like in their own neighbourhood using the data from the DIY sensors and the Bristol Open Data Platform. Bristol City Council built an open data sensor dashboard to enable the citizen scientists (and any member of the public) to interrogate the sensor data. The open data platform sensor dashboard has recently been discontinued by Bristol City Council. The dashboard enabled selection of a sensor via a map interface. The sensor data for a selected period could be inspected by means a time series function (time of day and day of week) and wind rose function (wind speed and

[11] intro_aq_open_data.mp4 and https://opendata.bristol.gov.uk/pages/making_sense_of_data/

direction). The data could be downloaded in a variety of formats. Through the data, the project could share evidence of peak events when the recommended World Health Organisation air quality guidelines and UK air quality objectives were exceeded. The project shared details of organisations locally and nationally who are campaigning for better air quality measures and introduced people to the website, https://addresspollution.org/ which allows visitors to input any address in the UK and gives an air quality estimation for that address.

Feedback for Workshop 1,2,3

KWMC evaluated the workshops with the citizen scientists using an evaluation form, as well as interviewing selected participants after the workshops. This provided a mix of qualitative and quantitative feedback about people's experiences of the workshops. Overall, the workshop attendants found it useful in understanding the wider air quality context of the project and how to use the data tools and making sense of the data presented. The recommendation they made for Bristol City Council is to add the total and average amount of time where sensors were above the WHO recommendation levels.

Participants reported on average a **high confidence in their knowledge about air pollution** after the workshops. All participants said that the workshops met their expectations, and that they had learnt something new. However, only half of the participants confirmed that something had changed for them after the workshops. Feedback included:

"I have a better understanding of air pollution, and also learnt more about ways in which I can help capture data for the benefit of the community"

"I will be much more aware of how much I use my wood burner"

"I feel more empowered to help my local community"

Three of the citizen scientists had wood burners installed in their homes. There were different responses on whether the engagement and being informed about the data around woodburning affected their choices in using their wood burners (Table 4).

Table 4: Feedback from three citizen scientists who own wood burners after Workshops 1-3

Participant	**Feedback**
Alan Citizen Scientist St Andrews Road, Montpelier Wood burner in home	*"It is understandable that people would want to have a woodstove and I am guilty of this very thing myself, however I do appreciate that most people don't need to burn the stove to keep themselves warm. If they do, that is a different matter. But **to make your house cozy and nice, I think people need to be made aware that these things are actually causing damage**, just in the way that cigarettes were realised to be causing damage some time ago." (October 2021)* *"I have **a better understanding** of the data around air pollution" (November 2022)* *"Yes, **being part of the project did change my choices around the use of my wood burner. I will minimise the use and burn only low moisture sawdust logs in DEFRA approved stove**" (November 2022)*
Colin Citizen Scientist Richmond Road, Montpelier	*"**I have a woodburner, my guilty secret**…….**I want some data to support what is merely a subjective judgement**." (October 2021)*

Wood burner in home	*"The project confirmed my view that periods of calm weather are times of worst air quality - but **evidence for the source of this was anecdotal and did not support the media reporting on the project**" (November 2022)* *"By being part of the project, **my existing position that the use of wood burners in calm conditions is unhealthy and to be avoided. I am most likely to keep using my wood burner this winter**." (November 2022)*
Ruth Citizen Scientist Horley Road, St. Werburgh's Wood burner in home	*"I **didn't know that burning solid fuel had such an effect**, and I would often put my Defra approved woodstove on. We don't use it very much... my parents live rurally, and they only use solid fuel to heat their house." (October 2021)* *"I will be **much more aware of how I use my wood burner**. " (October 2021)* *"More consideration on burning wood in the city" (November 2022)* *"No, **the project did not change my choices around using a wood burner**, I will very likely use my wood burner this winter." (November 2022)* When looking at the feedback from Ruth after the first workshop in October 2021, she stated that the workshop did change something for her and that she would be much more aware of how she used her wood burner. However, when she was asked the same question again in November 2022, she said nothing changed for her as part of being part of the project, and that she would likely be using her wood burner again this winter. It appeared that after the first workshop, the content was internalised by her, which impacted her choices. However, one year later, her feedback response appeared more generalised and it appeared that the project involvement had little or no lasting impact on her choices around using her wood burner. We asked Ruth to reflect on the finding and this was her feedback: *"to be honest, I think probably true… I was surprised at what I learnt re wood burning at the start of the project and it did make me more aware when using it. However, **I haven't ever relied on wood burning and only do it occasionally**- this hasn't changed since being a part of the study, I will continue to occasionally use the burner in the winter months.* *"…**with energy costs rising I have noticed lots of people on my road getting big loads of wood delivered, so I think people are turning to wood to heat their houses in the current cost of living crisis**…" (November 2022)*

After speaking with people who are affected by the smoke from people burning in their neighbourhoods, we were told that people were finding it difficult to directly address neighbours who use wood burners, and are many times met by animosity. We were curious whether the citizen scientists felt more confident on speaking with their neighbours about the health issues surrounding woodburning with neighbours and friends: 50% were very likely, while 50% were somewhat likely. We also asked how likely are you to become more involved in community projects or community action around air quality as a result of being part of the Slow the Smoke project? Out of the 6 responses, 2 were very likely, 2 somewhat likely and 2 likely.

Table 5: Feedback from three citizen scientists who do not own woodburners after Workshops 1-3

Participant	Feedback

Helmut Citizen Scientist City Road, St. Paul's No woodburner	*"I use my bicycle with my child everyday and **I'm just concerned about how high the air pollution levels are in Bristol**. Our experience is that is very stinky, especially in the morning while we're on the school run, I am surprised with how many cars only have one occupant. " (October 2021)* *"Proximity to bus stop and height of sensor installed affects pollution levels significantly" (November 2022)*
Carla Citizen Scientist Park Road, St. Werburgh's No woodburner	*"I'm **interested about air quality because of my family's health**. I know there are health impacts for my daughter and I want to see how I can help and get involved to combat it. **I notice the smell of woodsmoke in the area**, but I'm also concerned in particular about the pollution from cars and trains and the accumulative impact of that." (October 2021)* *"Just **good to see how the data is being gathered on a larger scale and to be able to make a small contribution** towards that." (November 2022)* *"It would be good to be sent a summary on if pollution levels varied with colder weather etc to help evidence speaking to others about their fuel burning practices." (November 2022)*
Iain Citizen Scientist. Shaftesbury Avenue, Montpelier No woodburner	*"I am interested to helping measure the air quality in my area, partly from a selfish perspective. **I have a daughter on the way, in three weeks' time. Ideally, I don't want her to grow up with poor air quality**." (October 2021)* *"My experience of air quality in my area hasn't been too bad, to be honest **I guess it is hard to tell as you can't see it,** so I think having the data on what the air quality is like is very important." (October 2021)* *"**I was much more aware of the types, causes and consequences of air pollution**." (November 2022)* *"**Satisfaction in helping to provide useful data** to help make the case for action in air quality." (November 2022)*

Workshop 4: Play Data with Play Wooden at Malcolm X Community Centre

To widen the reach of the project, KWMC co-organised this workshop with Play Wooden CIC (www.playwooden.co.uk), who run regular family play days at Malcolm X Community Centre in St. Paul's. It was a drop-in session, with a communal lunch provided. Using the existing networks of an embedded organisation within the community, ensured good and representative attendance for this workshop. People felt the trust and familiarity to attend a meeting about the topic of air pollution by an outside organisation. The main aim of the workshop was to get a better understanding of air quality in St.Paul's, through data and people's lived experiences. By using the Bristol Open Data platform, we were able to compare the data we collected with the Sensor.Community sensor at the Malcolm X Community Centre with data from the reference analysers owned by Defra and Bristol City Council in St. Paul's and the city. To understand people's experiences, we did an interactive session looking at problems and exploring solutions. The outcome of this identified common themes, which we were able to build on at the following workshops.

Figure 9: Pictures of the Play Data workshop with Play Wooden

Table 6: Feedback from participants at the Play Data workshop

Participant	**Feedback**
Tara St. Paul's Resident, Inclusive Communities Facilitator (Bristol City Council)	*"The way that Knowle West Media Centre and Play Wooden have done this consultation today was **very friendly for the community**. Hopefully we can co-design and co-create the solutions with you. **I would recommend this kind of consultation for other organisations to do**."* *"**I feel better informed, but I feel more worried** for us residents' health and wellbeing. People who are better off can move out of the community, but most of us can't move out, **the inequalities are very clear**. "*
Sarah St. Paul's Resident	*"Loved having Play Wooden here, it was a welcome addition, for the kids being played with and looked after."* *"I do think differently after the workshop, **personally I don't know if there is anything I can do to change it**, I do realise it's a bigger issue, I guess everybody walking and using public transport, but there is a bigger picture that needs to be addressed."*
Tilly – St. Paul's Resident	*"Good having the children activities, this means I can actually come to something like this."* *"It has been good to focus on the topic of air pollution properly. Seeing the data in front of me and seeing the word -cancer- and -heart problems- pop up. **I always had it in my mind, but it has really focused it for me**."*

Happy - St. Paul's Resident	*"**My baby daughter is pre-mature, her lungs are not well developed according to the doctor. Air quality is really a concern for me and my family**. I personally would like the government to encourage more public transport – restrictions on issuing car license, encouraging e-vehicles. They might be on the right track, but need to take more* steps."
Anon *St. Paul's Resident*	"*I have asthma. I moved here 1 year ago, **I feel my asthma is high, especially in the winter.** Everyone wants to use cars. My husband has a car, I don't have a car, I walk. I would like to see more buses in the area, they are not good. If I am in the City Centre with my children, when I want to go back, there is no bus. Then I have to take a taxi, or have to walk home with my kids."*

Workshop 5: How do we tackle air pollution in St Paul's? A Solution focused design workshop at St Werburgh's Community Centre

In addition to capturing the local experiences and ideas, this workshop focused on designing solutions to the problem of air pollution in the neighbourhood of St Werburgh's, while building on the ideas and suggestions which were developed in the workshop in St. Paul's (Workshop 4). Two themes were highlighted in particular:

1. Ambient air pollution exposure of young people on the school run to St Werburgh's Primary, including the problem of parents driving to drop off their children.
2. The lack of clear information and legislation as well as "greenwashing" around woodburning, leading to assumptions that it was an eco-solution.

Figure 10: Pictures of the Solutions focussed workshop in St Werburghs

Discussion amongst the group included car drivers' reluctance to change behaviour, waiting for electric cars to become mainstream; the government's lack of prioritising air quality as a health emergency and not taking action on the issue. At the end of the workshop there was a feeling of powerlessness in acknowledging the energy and effort it takes from within communities themselves, as the government would not take action unless people put pressure on them.

Table 7: Feedback from participants at the Solutions Focussed workshop

Participant	Feedback
Anon *Mother of young children*	*"**Our children are worst affected, the data doesn't show the exposure my child is directly experiencing** twice a day walking along that road with all the cars running their engines while stuck in traffic. As parents, we don't have the energy to be able to take this action, who can do this?"*
Kay St Werburgh's resident	*"I **learnt about biomass boilers that I had no idea about that they weren't at all green**. which I did not know about and how damaging they were. Even so, learning about them, doesn't mean that I know what to do about them."*
Gavin St Werburgh's Resident	*"**I'm more keen to do something about it, if you can find a local councillor who is interested to talk through some possible actions**."*
Sheila Workshop Participant	*"I'm very pleased to say that **even though we had a small amount of people from different areas, that actually they all engaged, and I think we all learned something**."*
Rhian Ashley Resident	*"We live on old Ashley hill, we get an awful lot of traffic, and we are up the hill so **in the winter when everyone gets their wood burners on we can feel the smoke**, especially on a clear cold day. **Sometimes it feels very heavy, if that is a way to describe it**"* *"What I heard, has concerned me a lot especially with young children. **Definitely sparked my thinking to learn more and think more about getting in the car, short journeys and things like that**..."*
Anon *Mother of young children*	*"...even though I understand that the air quality exposure is bad, it doesn't feel like an immediate threat. **Somehow, I don't feel the urgency to do anything about it, it's like there is a disconnection**."*

Workshop 5 and 6: Sonification – turning air quality data into a new sonic artwork

KWMC commissioned an artist to explore the air quality narrative by converting the data into a new sonic artwork. Miriam Quick (https://miriamquick.com/, podcast https://www.loudnumbers.net/) is a journalist, author and musician who explores novel and diverse ways of communicating data. She co-creates artworks that represent data through sound, images and sculpture. These have been exhibited at museums and galleries internationally.

Miriam accessed the data from the citizen scientists' low-cost air quality sensors via the Open Data Bristol portal and used it, along with data gathered by Bristol City Council, to create the music track. Miriam used the PM_{10} from the 14 different sensors in Ashley Ward, over the course of the year from August 1, 2021 to July 31, 2022. As the sensors showed broadly similar readings over time, she

took the average reading across all sensors and then the average by month – reducing hundreds of thousands of datapoints to just 12. This revealed that, on the whole, particulate levels are higher in the winter months.

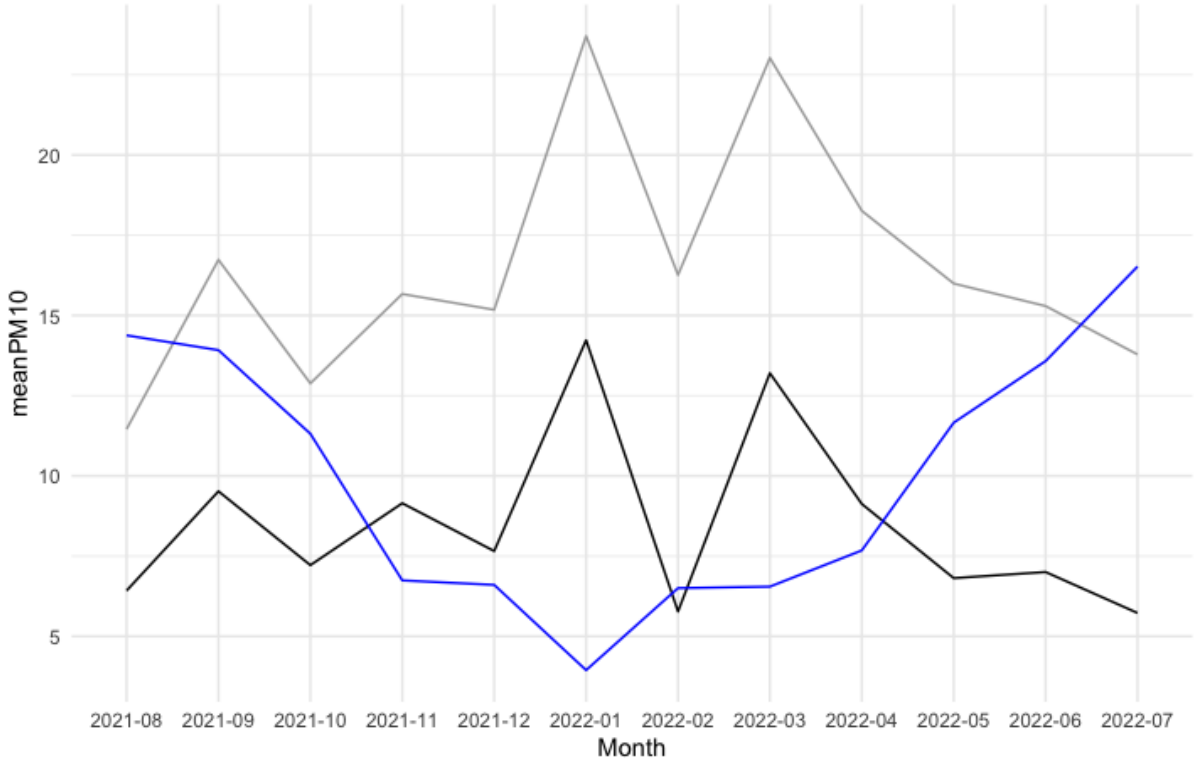


Figure 11: Time series of sensor data at AURN St. Paul's (next to St. Paul's Nursery School) showing monthly average PM10 (light grey), PM2.5 (dark grey) and temperature (blue).

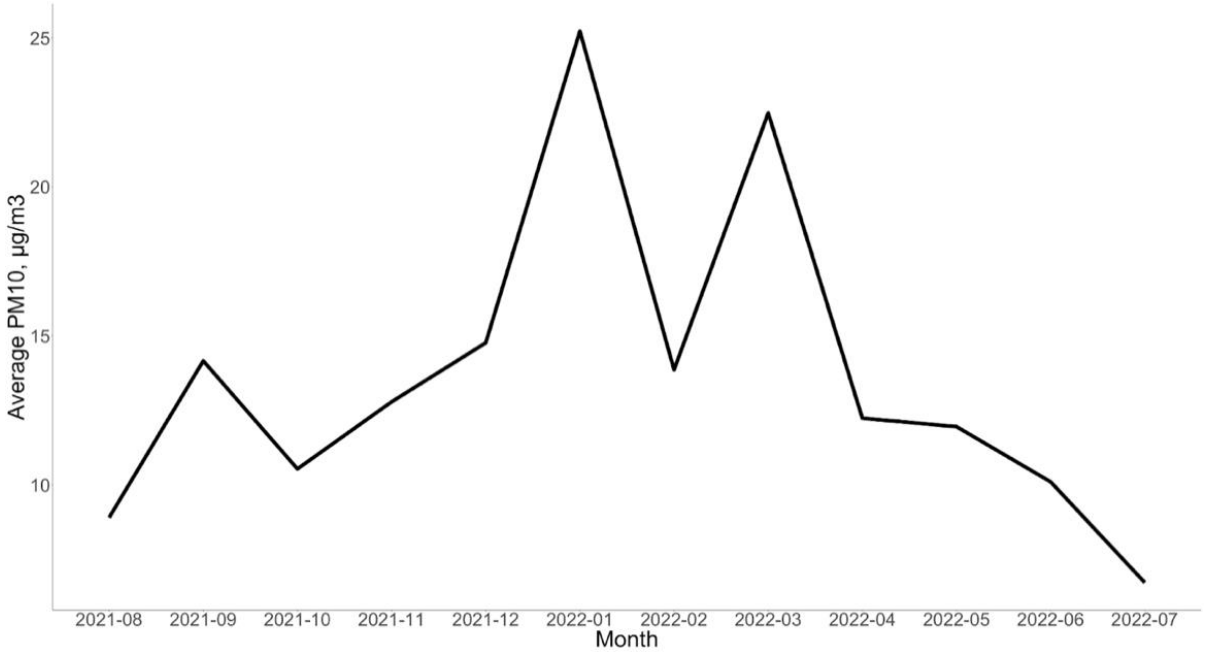


Figure 12: Monthly average particulate matter (PM10) levels for 14 sensors in Ashley Ward, Bristol from August 2021 to July 2022

It was observed that air quality deteriorates in the winter in Ashley Ward and improves in the summer. The assumption is supported by how people behave during the winter months, with more people driving their cars and lighting their wood burners when it's cold outside. This behaviour is also exacerbated by winter meteorological conditions with more inversions (i.e. cold air sinks and traps air pollution near to the ground, especially when there's little wind).

Transforming the data into music:

This broad seasonal pattern exhibited in Figure 11 and Figure 12 is the focus of the music track. The Software used to create the sonification includes R studio for analysis of the air quality data; Sonic Pi / VCV rack for sonification; and Logic Pro for music production.

There are two main layers to the sonification.

1. Firstly, there is a nasty-sounding drone that gets louder and harsher as the air gets dirtier in the winter. The data is mapped to the volume and cut-off of a low-pass filter. When the air quality is bad, this drone is so loud it dominates everything. It's supposed to sound horrible! When the air cleans up again in the spring, the drone gets quieter and fades out.
2. Secondly, a dub track plays at the same time as the drone. It responds to the data in the opposite way: instead of getting louder when levels are higher, the music gets quieter. This music track is representing the people living in Bristol. When air quality gets bad in the winter, it's like the drone is drowning people out and stopping them from living their lives. Which is exactly what air pollution does, even at low concentrations: it makes us ill and stops us living our lives to the full. You don't hear the music at full volume until right at the end of the track, when you realise what you've been missing the whole time.

Adding lyrics and the citizen voice

T.Relly, is a renowned hip-hop artist in Bristol who grew up in St Paul's neighbourhood. T.Relly has links with the city' major club nights, but also a passion and support for Bristol's most disadvantaged through his work in youth services and with prison leavers. He created the vocals and wrote the lyrics, which adds commentary and an invaluable human dimension to the data.

The aim of the workshop was to record sounds from the community and to introduce the concept of sonification through various activities. We set up the room into stations, where the participants could go on a journey through the artists' process of:

1. understanding air quality data;
2. exploring sonification by experimenting with sound making with data activities; and
3. recording their sounds and voices to be added to the track.

In the track you can hear the names of the months spoken out loud (August, September and so on), like audio labels telling you what point you are at in the year.

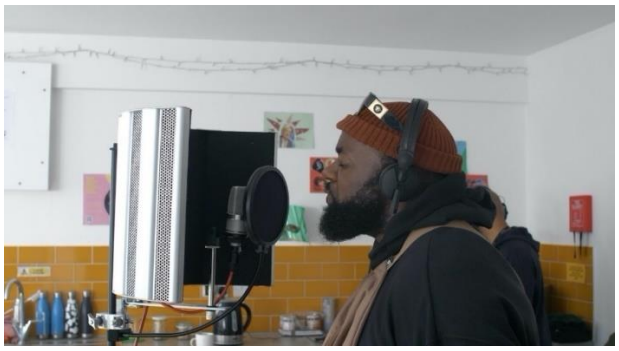
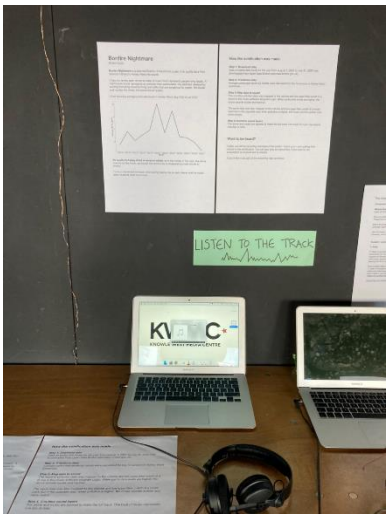
Recording session T.Relly at Hamilton House, Stokes Croft, St. Paul's	
The room was set up in different stations, which worked very well within the space and to accommodate people who came at different times.	
This was the listening station. Listen to the track and get an overview of the sonification process and the meaning of the different sounds, especially the drone used in the track	
Percussion artist, Ed Allen had a selection of "sound making objects". Some of these included objects which could mimic the wind, or rain. Children also enjoyed making their own drums.	

Figure 13: Images of the recording process for the Slow the Smoke sonification activity

The artist, Miriam Quick designed a selection of sonification activities. They all explored data and sound making at different degrees of complexities. One activity, Play the Weather (see Box 1) explored weather data; wind and temperatures. People could join in this together as a group, it was physical and fun. It was a novel experience for many, especially the children enjoyed the process and excitement to be featured on a music track.

"When you play the music quieter it feels peaceful, and then it gets intense and your body reacts with that. I think it is a good experience for the children especially. ***It was good to understand how your body changes and your senses and then think about pollution and looking at data more closely and really interpreting that through using your senses and sound,*** *it was great."*

Tara, St.Paul's resident and workshop participant

"I liked the approach of translating data into sound, so that ***it is able to touch people emotionally and not only convince them to change behaviour based on reason****."*

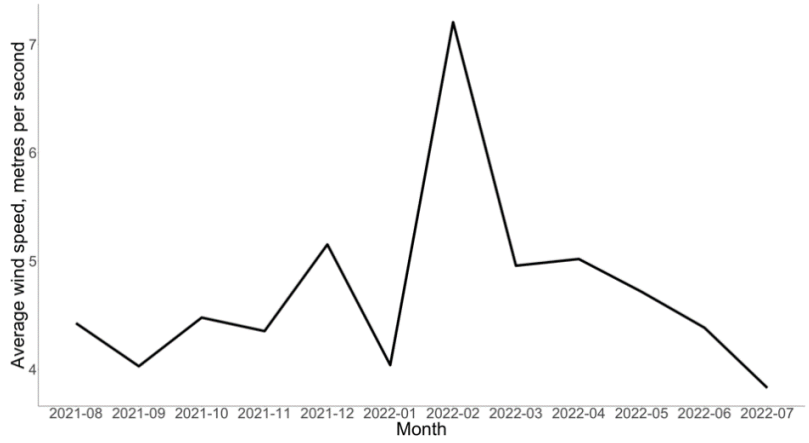
Anon, Workshop Participant

The final recording can be heard here: https://www.youtube.com/watch?v=AhWWO0EtM1c

Box 1: Activity: Play the Weather - Wind

This line chart shows the average monthly wind speed in Bristol over the past year.

Let's turn this data into sound!



What to do

Choose an instrument to represent the wind.

Try to play the line. When the wind blows faster, change the sound in some way.

The faster the wind, the more the sound should change in that way.

For example, you could:

Play louder: the faster the wind, the louder the sound.

Play higher notes: the faster the wind, the higher the notes.

Play faster: the faster the wind, the faster the sounds.

Tip: Have a steady beat in your head or ask someone to tap a steady rhythm along with you. Count one beat for each month.

Workshop 7: Minecraft - gaming as a form of air quality data storytelling with young people

The project was very eager to engage young people. Working with the Docklands Youth Club, through one of our citizen scientists who worked with young people, the project used a Minecraft game design, to raise awareness, inform and educate about air pollution in St. Paul's. This part of the project was also supported with funding from the Parcos Project, a Horizon 2020 funded research project about participatory science (https://parcos-project.eu/).

The team consisted of Dan Tagg, a creative technologist from Wildman and Herring Ltd (http://wildmanherring.com/) who has experience of manipulating Minecraft for educational purposes, to support the data narrative within the game. The project received support from the outreach team at University of West of England Digital Engineering Technology and Innovation group (UWE DETI), who has experience in delivering workshops with young people using Minecraft as a tool to encourage young people to think more creatively about engineering.

We offered the workshop during two youth club settings, one in St. Paul's, in the locality of the Ashley ward and one in Knowle West at KWMC. The young people attending both the sessions have played Minecraft before, with different levels of experience. The intention of the workshops was to involve the participants in the co-design of the Minecraft game as a tool to educate young people about air pollution. We had breaks to get feedback on their experience and the opportunity to observe their interactions and their design choices. A total of 13 people attending the workshops. There was a low attendance at the youth club settings themselves, likely due to adverse weather on both evenings. (all the young people who attended the sessions, were playing Minecraft.)

However, the learnings from the workshops were very useful to support the game development and how to frame the content in a timely manner, responding to how the individuals play the game. It was especially helpful to inform us how to interject the fun element consistently during the game. The young people were 100% engaged throughout both the sessions and they reported the session as "fun".

Figure 14: Participants at the Minecraft workshops in October 2022

The Aim of the Game

The aim of the game is to lower air pollution for the neighbourhoods in the Ashley ward. The game is played in *Creative Multiplayer Java Mode* and utilises the private Minecraft server set up at KWMC. Installing the game on multiple laptops gives potential to travel the workshop to other groups in the city. Whilst the multiplayer mode is a very important part of the game, it requires a robust internet connection to play. If this is not the case the realm can still be played in single player mode. The project found that the social interaction in the multiplayer mode a very important motivator for the groups.

Creating the Bristol world in Minecraft

We imported a rendered map for the neighbourhoods of St Paul's and St. Werburgh's into Minecraft, which was provided by UWE DETI, created by their partners at Atkins. Within the map, we identified three zones (Figure 15), which was a very important design element of the game. The areas were highlighted to achieve the aims of the game, but also held significance based on the experiences of our citizen scientists and residents who attended previous community workshops in

St. Paul's and St. Werburgh's. The three zones support the translation of the real-world map into Minecraft. The three zones are:

- Yellow Zone is focused on St. Paul's Adventure Playpark, which is adjacent to the M32 motorway;
- Red Zone includes the congested Mina Road, used as a cut-through the neighbourhood by vehicles to and from the M32 motorway; and
- Green Zone includes St. Werburgh's Primary School and Nursery, where families are exposed to ambient air pollution from idling cars stuck in traffic during the school run.

The zones also allowed the activity to focus the interventions in the game design, whilst preventing people to drift off and lose interest. Colour coded beams supports the players to navigate around the zones within the world and to help them find other players.

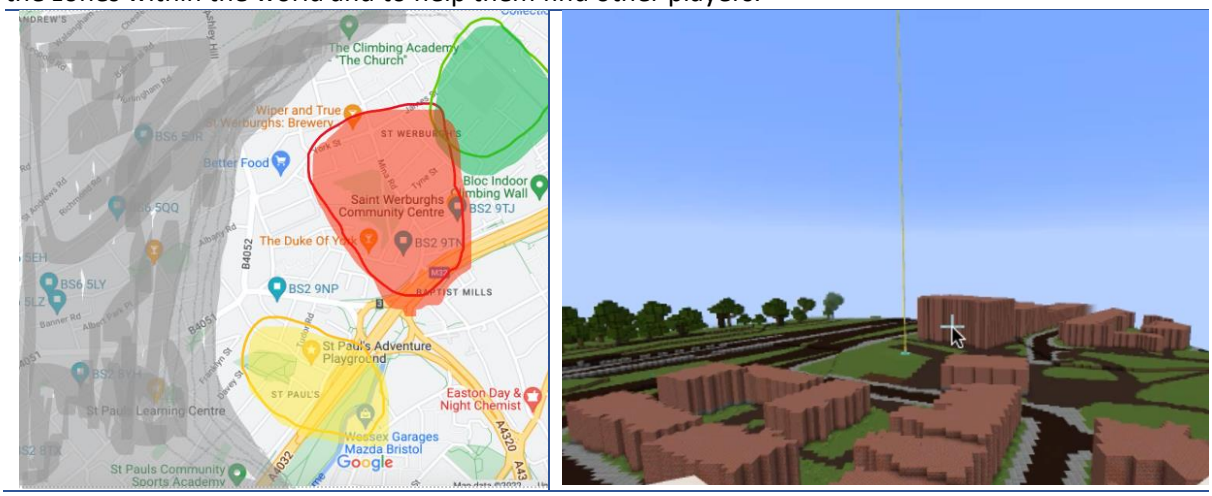


Figure 15: The different zones in the Bristol Minecraft world (left) and the different colour beams supported navigation in the Minecraft game (right)

Creating the Data Narrative within the game

The aim was to represent and communicate the air quality data within the Minecraft world and for this data to be gamified, thus informing the progress status of the players. If the air quality values are low, they are successful, if the air quality values are high, they need to take actions. The data from the citizen scientists' low-cost sensors showed similar results of PM_{10} and $PM_{2.5}$ at different sensor locations within the neighbourhood, so we decided to use one set of data values to represent the whole Minecraft world.

Gamifying the data

To differentiate between high or low air quality data values, we aligned the air quality data values with the colour of the sky, showing red when the levels were high, and a bright clear sky when the values were low. However, when playing the game, we observed that Minecraft follows its own timeline, which also changes the colour of the sky during daytime or nighttime. We overcame this by supporting the functionality with pop-up messages for the players, to indicate the air quality values: showing the number, as well as whether it was high or low, with a prompt to take action. These pop-up messages could also be added manually while playing the game by the facilitator, thus responding to the actions (or inactions) of the players. We identified three activities within the game which impacted air quality data values, when performed by the players. These were putting fires out, removing cars and planting trees. Playing in multiplayer mode (collectively) all of the actions from the players working together affect the air quality levels in the Minecraft world (Figure 16).

The actions were introduced systematically by the facilitator during the game under the three themes: transport, heating our homes and the number of trees and green spaces in our neighbourhoods. After each action was introduced, and experimented with by the players, there was an opportunity to break out for a discussion about the theory around the topic and to expand

on this task in prompting the players to come up with better design solutions for transport, heating our homes and urban design. This allowed for creativity from the players and the outcomes were shared with the group at the end of the session.

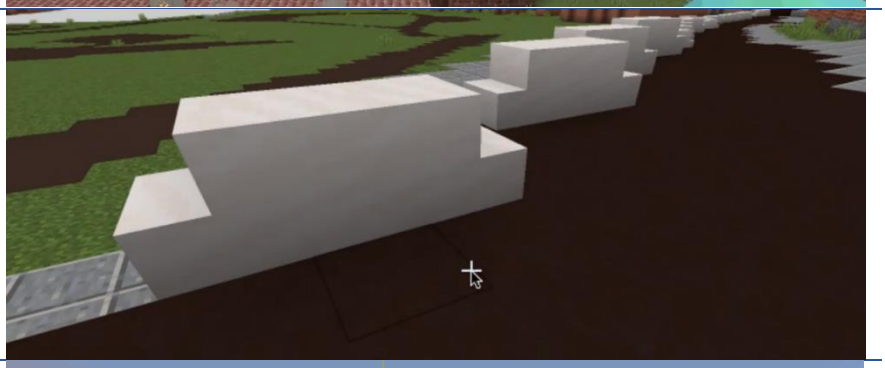
Activity 1. Putting the fires out coming from the buildings and design better solutions to how we can heat our homes	
Activity 2. Remove the cars and design better transport solutions	
Activity 3. Plant more trees and redesign urban environments	

Figure 16: The different activities in the Bristol Minecraft world

Observations of the game

The following observations were made of the game and activity (also see Figure 17).

- After putting out the fires, one of the players put solar panels on roofs, another player added bicycles after removing the cars. All the players enjoyed planting trees and creating forests.
- One player introduced animals, others followed suit and started farming, allowing for conversations around locally grown food vs transporting it from other areas.
- One of the players introduced bees and planted flowers, which led to conversations about biodiversity and how bees and birds are also affected by poor air quality and lack of bee friendly fauna and flora.

- When the player introduced the bicycles, another player started removing the bicycles, which led to a conversation about everyone doing their bit and an understanding of working collectively.
- Group 1 in St. Paul's, who were all friends, immediately looked for each other inside the game and built houses next to each other. They were able to recognise landmarks and have a familiarity with the area.
- Group 2 in Knowle West were playing in the same world, which was not their neighbourhood consequently not familiar to them. They teamed up with the person next to them by finding them within the game using the locator.
- A more experienced player introduced humans, who needed to be given homes and jobs to carry out - otherwise they would start fires and cause havoc! This added a lot of fun to the game and was a good way to inject jeopardy complication to the game.
- The players who had more experience supported the newer players

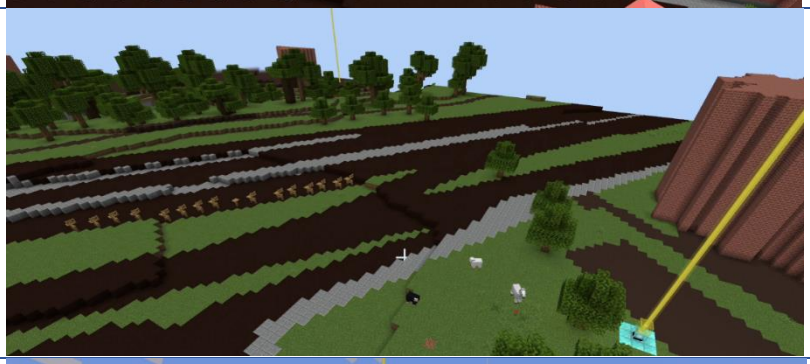
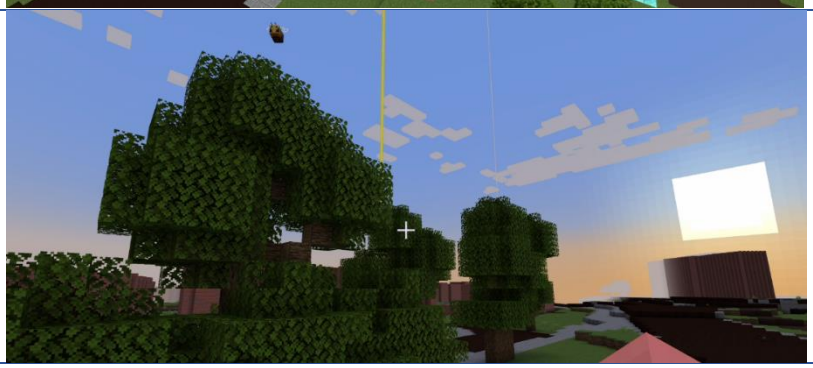
Solution 1. Solar panels on roofs as solutions to heating our homes	
Solution 2. Introducing bicycles as solutions to cars on the road	
Solution 3. Introducing bees and urban gardens	

Figure 17: Visualisations of different solutions in the Bristol Minecraft world

Overall, the Minecraft approach was an excellent mechanism to engage young people in the discussions around air pollution include understanding the sources, data and solutions. Participants stated that they found the minecraft workshops "*Fun*"; they *"….learned about air pollution*"; and they *"….. would play it again*".

Workshop 8: Showcase Event *Bristol Burning (A Bonfire Nightmare)* Track Debut

Slow the Smoke had a final event and showcase on Bonfire Night, 5 November 2022 in Bristol, where we showcased all the findings from the Slow the Smoke project through data, citizen science, community voices and art. An exhibition showcasing the different data narratives as interpreted by the community, gave visitors an insight into the project.

The highlight of the evening was the debut of the artist commission, *Bristol Burning (A Bonfire Nightmare)* accompanied by an animation created to support the data narrative. The track was followed by a Q&A with both artists Miriam Quick and T. elly, to be turned into a podcast and released alongside the track with an accompanying video planned for early Spring 2023. The track was well received, however because of the acoustics in the venue, some of the lyrics got lost as the track is very reliant on a good bass speaker. We are working with the artist to remaster this.

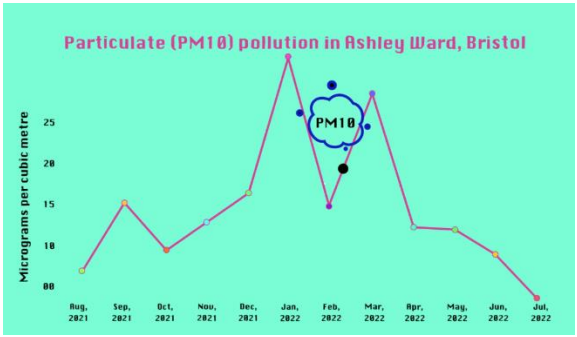


Figure 18: Animation showing the data narrative and Q&A with the artists Miriam Quick and T.Relly

During the event we started conversations with local community members about next steps to inform the launch of the track. As part of our engagement using the Bristol Approach, we designed assets with the community, however these needs to be placed back in the hands of the community. As a continuation of the project, KWMC will work alongside people and organisations from the neighbourhoods involved in the project and local press to plan and release this track as part of an air quality awareness campaign, which is citizen led. We finished off the evening with a delicious meal prepared by a local chef in St. Paul's, allowing for more conversations and networking.

The participants stated that the final workshop was an "important showcase" and *"the agenda of the evening made the approach accessible and was consistent."*

4 Gathering Robust Data on Solid Fuel Use and Behaviour Change

Over the long term, the impact that the project and other national interventions have on $PM_{2.5}$ concentrations could be measured using existing and new air quality monitoring networks. However, in the short term there are many confounding factors that impact upon measured air pollution concentrations that will make it difficult to judge the success of the project through monitoring alone. To provide a more robust assessment of the effectiveness of the project in terms of raising awareness and changing behaviour, two surveys were conducted.

Two online surveys, managed by Bristol City Council, explored attitudes, awareness and behaviours to solid fuel and uncontrolled burning. These surveys allowed Bristol City Council to collect valuable information on solid fuel use habits and to determine the effectiveness of the project in influencing positive behavioural change to reduce emissions from solid fuel.

The University of the West of England's Air Quality Management Resource Centre (UWE) provided support in analysing the survey findings. The two surveys were broadly identical except for two additional questions for the post-Slow the Smoke Project survey to evaluate if the project had raised awareness of solid fuel burning and the impact of air pollution. The two additional questions in the second survey were:

1. Have you been aware of the Slow the Smoke project in Bristol to raise awareness of solid fuel burning and the impact on air pollution?
2. If yes, has Slow the Smoke improved your knowledge about the following? (Please select any for which your knowledge has improved).

The survey questions and structure can be found in Appendix A.

Survey Methodology

1. Both surveys were designed and implemented by Bristol City Council with contributions from Bristol City Council staff and local councillors, UWE and KWMC staff.
2. Both surveys incorporated open and closed questions.
3. Both surveys were managed by Bristol City Council's Communication and Engagement Team using the Council's online survey tool.
4. The survey was promoted via the Council social media teams.
5. Survey 1 was launched in November 2021 (pre-Slow the Smoke Project) and Survey 2 was launched in November 2022 (post-Slow the Smoke Project)
6. The data was anonymised by Bristol City Council before being released to UWE to ensure compliance with ethics and data protection.
7. The data was analysed using SPSS and QGIS.
8. The Data Dictionary for the two surveys can be found in the Appendix A.

For the purposes of this report, the survey data is assessed across five themes:

1. Participant details (Q16, Q17 and Q18)
2. Perceptions and concern about air pollution (Q1, Q2, Q3, Q9, Q10 and Q11)
3. Home heating practices (Q4, Q5, Q6, Q7 and Q8)
4. Action for reducing pollution (Q12 and Q13)
5. Comparison of solid fuel use against Indices of Multiple Deprivation
6. Impact of the Slow the Smoke initiative (Survey 2 only – Q14 and Q15)

Care should be taken when interpretating the findings due to the relatively small survey response rates and the lack of representivity of the data.

Participant details

A limited amount of personal information on the participants was collected to ensure anonymity. For example, no demographic data such as gender, age, ethnicity, income levels etc was collected as it was perceived that this might put off participants and it was not thought to add substantial value to the data analysis. Data was collected on:

- participants postcode (Q16);
- if they own or rent their home (Q17); and
- the type of home that they lived in (Q18).

The purposed of these questions was to allow for cross-tabulation of responses with other questions and data. For example, the postcode data was used to make cross comparisons with deprivation data using QGIS. A summary of the responses for Q17 and Q18 is provided in Table 8. Survey 1 has 249 respondents while Survey 2 had 274 respondents.

Table 8: Survey participant details

Q17: Do you own or rent your home?				
	Response %		Response Total	
	Survey 1	Survey 2	Survey 1	Survey 2
Own (or mortgage)	82.4%	83.5%	201	222
Rent	17.6%	16.5%	43	44
No reply			5	8
Q18: What type of home do you live in				
	Response %		Response Total	
	Survey 1	Survey 2	Survey 1	Survey 2
House	82.1%	81.4%	202	219
Flat / Apartment	13.4%	16.0%	33	43
Maisonette	1.6%	2.6%	4	7
Bungalow	2.4%	0%	6	0
Caravan / Van	0.4%	0%	1	0
No Reply			3	5

Perceptions and concerns about air pollution

This section explores the participants response to questions related to:

- sources of pollution (Q1);
- concern about pollution (Q2);

- perceptions of improvement in air pollution in the last five years (Q3);
- concern specifically about indoor solid fuel burning (Q9);
- the reasons for this concern (Q10); and
- if they had noticed a difference in solid fuel burning in their neighbourhood (Q11).

A summary and description of the findings are provided below. There are three notable factors which should be considered when reviewing the data:

- The Bristol Clean Air Zone was launched in November 2022.
- A substantial increase in the costs of living, especially energy costs, between November 2021 (Survey 1) and November 2022 (Survey 2).
- The weather leading up to November 2022 was relatively mild.

As the second STS Survey was live in November 2022, the shift in responses between Survey 1 and Survey 2 may be a reflection of these three factors.

Across both Survey 1 and Survey 2, roads are considered the dominant source of air pollution followed by smoke from solid fuel burners. Other sources of concern include bonfires, trains, gas boilers, industry and agriculture (Figure 19). Between Survey 1 and Survey 2 there is a notable increase in the perception of roads being the dominant source (increase from 70% to 84%) and a decrease in the perception of smoke from solid fuel burners being the dominant source (decrease from 20% to 9%). These finding is further contextualised by respondents who stated:

- *"The main and overwhelming source of pollution is motor vehicles"*
- *"Solid fuel isn't an issue. High traffic is"*
- *"The war in Ukraine is going to influence how people will heat their homes this winter"*
- *"With the rising cost of energy use this can only get worse."*

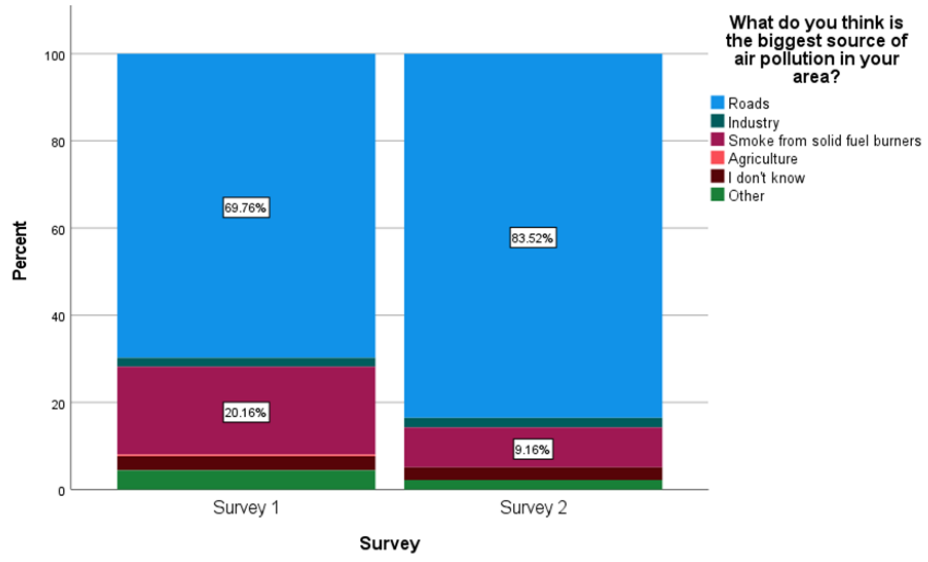


Figure 19: Source of air pollution identified by participants.

Across Survey 1 and 2, the majority of respondents had an overwhelming concerned about air pollution (Figure 20) but a smaller majority was concerned about indoor solid fuel burning (Figure 21). However, it is notable across both surveys, a statistically significant proportion of respondents ($p < 0.001$) who did not own a solid fuel fire / stove stated that they were concerned about indoor solid fuel burning (Figure 22). The overwhelming reason in both surveys for concern about indoor solid fuel burning was that it was bad for my / my family's health (91% and 88% respectively in Survey 1 and Survey 2) . The general perception was that air pollution is deteriorating with

approximately 50% of responses in Survey 1 and Survey 2 stating their concern (Figure 23). Respondents voiced their concerns by stating:

- *"Asthma getting a lot worse over recent years.....I think is the reason for deterioration (is) increase in wood burners in this area. They are regarded as a "trendy" accessory".*
- *"The reason being a number of residents (myself included) own a clean burn stove but no longer use it due to the impact on the Bristol air - we do not wish to contribute to the problem."*
- *"I had no idea that burning solid fuel in this area was problematic, I know air quality is poor but believe it to be related to the huge amount of traffic entering the city centre."*

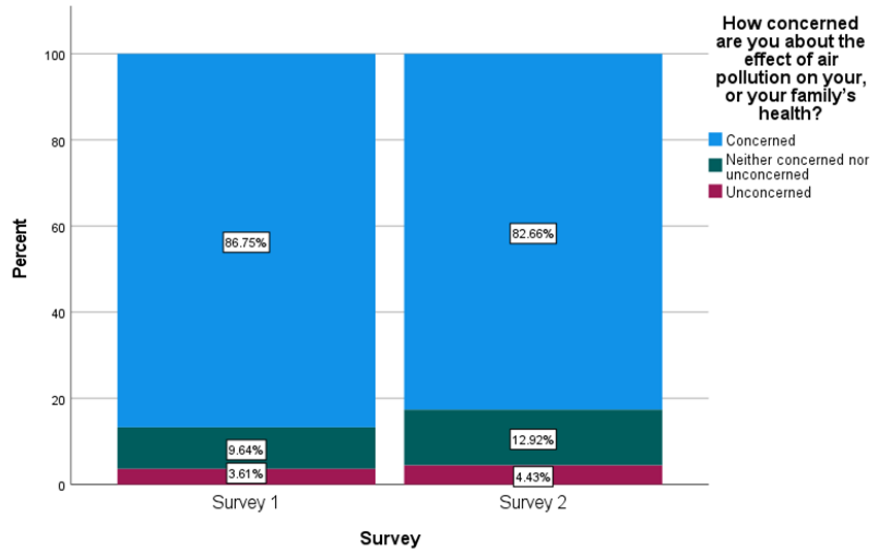


Figure 20: Public concern about air pollution

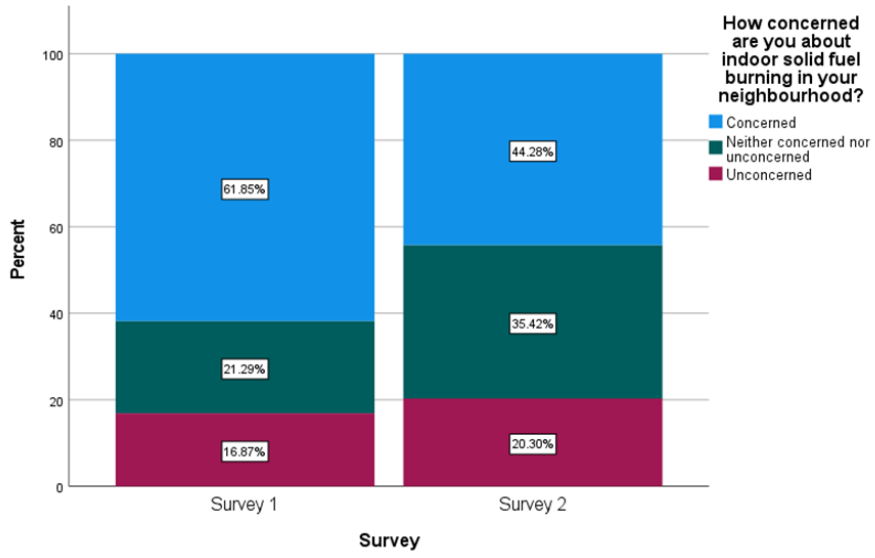


Figure 21: Public concern about indoor solid fuel burning

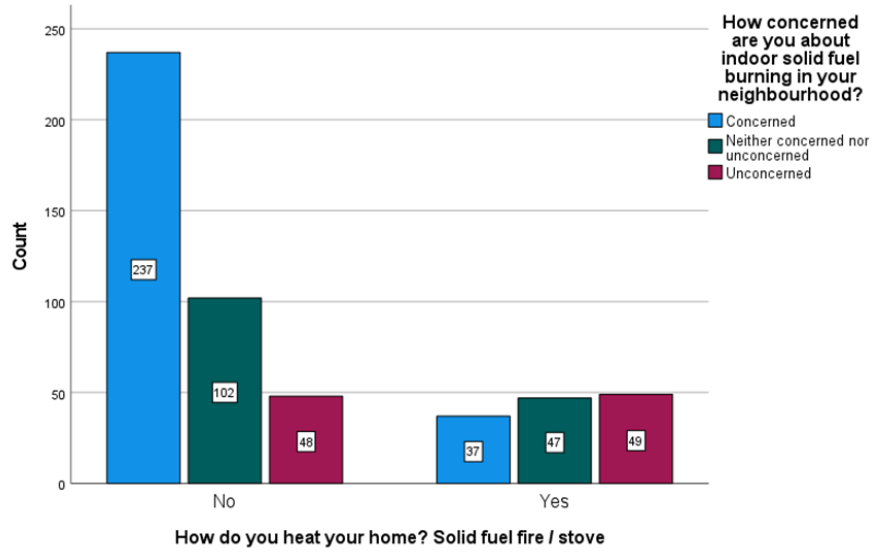


Figure 22: Public concern about indoor solid fuel burning based on ownership of a solid fuel fire / stove

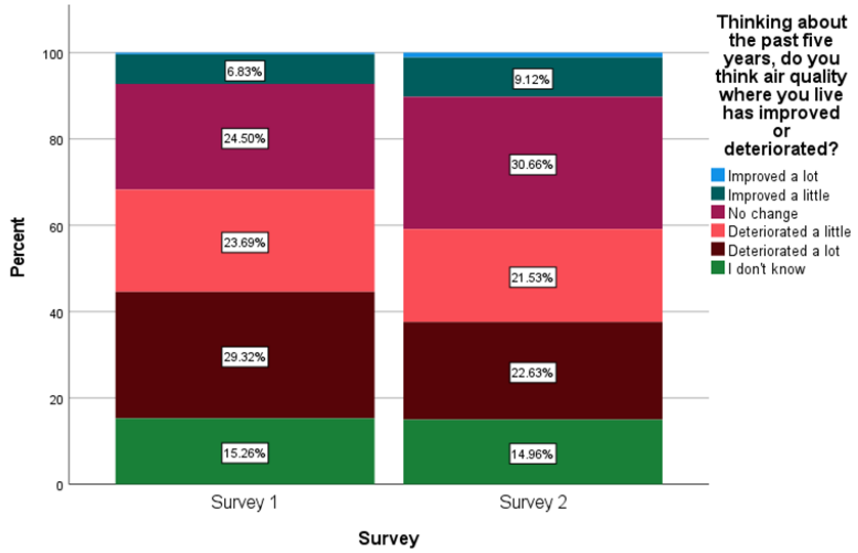


Figure 23: Has air pollution deteriorated in the past five years?

Only asked in Survey 2, 29% of respondents stated that they had observed an increase in solid fuel burning in their neighbourhood in the last year (Figure 24). This lean towards an increase in solid fuel burning is perceived to be related to the cost-of-living crisis. One respondent stated: *"I am aware of a number of people who have purchased wood burning stoves or prepared traditional fires for use due the increased cost of gas heating, as well as other people buying substantial amounts of wood rather than just a bag or two they used previously for the occasional fire due to the cost of living crisis."*

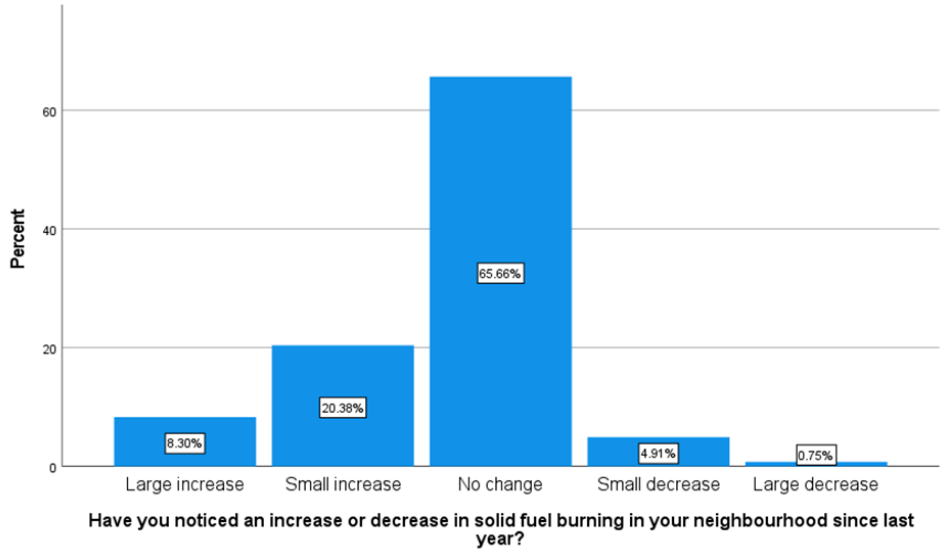


Figure 24: Any noticeable increase or decrease in solid fuel burning in your neighbourhood in the last year?

Home heating practices

This section explores the participants response to questions related to:

- how they heat their home (Q4);
- types of fuel used (Q5);
- types of appliances used (Q6);
- frequency of solid fuel burning (Q7); and
- the reasons for solid fuel burning (Q8).

A summary and description of the findings are provided below. Please note, many of these questions were multiple choice questions so respondents could provide more than one answer.

When asked in both Surveys, how do participants heat their home (Q4), gas central heating dominated as main source of heating (90%) followed by solid fuel burning (26%) and electric heater (16%)(Figure 25). There was a small increase in the number of respondents that used solid fuel between Survey 1 and Survey 2 but it was not significant. More than 92% of respondents that had solid fuel burning also had an alternative heat source (primarily mains gas) indicating that solid fuel burning is a supplemental heat source. Only four respondents had solid fuel burning as their only source of heating). In comparison, the DECC, 2015[12] study found that 7.5% of households were using wood fuel in UK (12.6% in the southwest) and the KANTAR, 2020[13] study found that 8% of households were using solid fuel burning in UK (9% in the southwest). Most respondents who had solid fuel burning owned their home (93%) and most solid fuel appliances were found in houses rather than apartments or bungalows (96%). The recent Chief Medical Officers Report on Air Pollution[14] stated that in the UK, about 1.5 million households burn wood and just under 400,000 households use coal and other solid fuels. Although some households depend on this solid fuel burning for space heating, many homes burn solid fuels in conjunction with other space heating methods for heating and for aesthetic purposes, especially in urban areas. This concept of aesthetic or recreational pollution is a relatively new challenge for air quality and public health management

[12] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/517572/Summary_results_of_the_domestic_wood_use_survey_.pdf

[13] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20159&FromSearch=Y&Publisher=1&SearchText=AQ1017&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

[14] Chief Medical Officer's Report 2022: Air Pollution - https://www.gov.uk/government/publications/chief-medical-officers-annual-report-2022-air-pollution

to address. The concept goes beyond just solid fuel burning to also incorporate other indoor and outdoor pollution issues e.g. burning of incense, recreational driving etc. To address this, management approaches need to go beyond techno-centric solutions and consider how household behaviours and practices can be positively influenced.

When asked what types of fuel they burn (Q5), dry seasoned wood dominated (88%), followed by smokeless fuel (25%) and other fuels mentioned include waste wood and wood-chip briquettes. In comparison, the DECC, 2015 study found that 92% of households were using logs and the KANTAR, 2020 study found that 89% were using wood

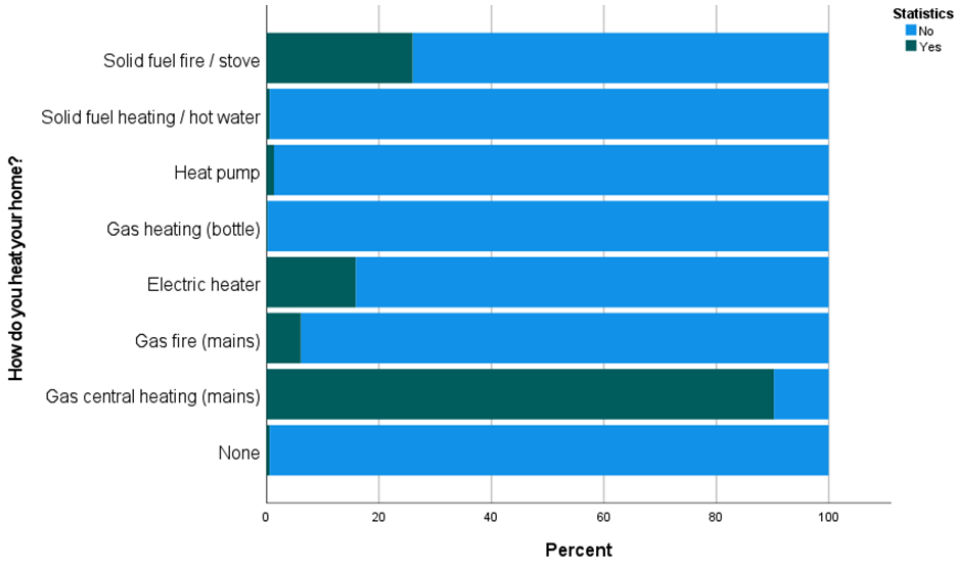


Figure 25: How respondents heat their home

When asked what kind of appliance they used for burning solid fuel (Q6), more than half the respondents stated that they use and eco-design stoves (51% and 58% in Survey 1 and Survey 2 respectively) with the other half split between a stove and an open fire (Figure 26). Some respondents provided positive behaviors and observations of using solid fuel burning:

- *"The extremely efficient, small, clean burn, DEFRA approved log burner I use with kiln dried hardwood is now the least expensive, least polluting option available when used properly. I only need to burn one good log per evening during the coldest spells in mid winter, heating just one room in the house."*
- *"I burn wood that is clean and has been seasoned for 2-3 years. I do not burn coal. I do not get wood from a skip . I do not burn wood that has been painted. I have a woodburner that is DEFRA recognised and burns hot so there is very little to clean out in the morning (it burns twice)"*

1. *"Our wood burner means we can massively reduce our reliance on gas for heating. Education re wood stove standards and use of seasoned woods has great merit but the debate needs to reflect the nuance and complexity that the subject involves"*

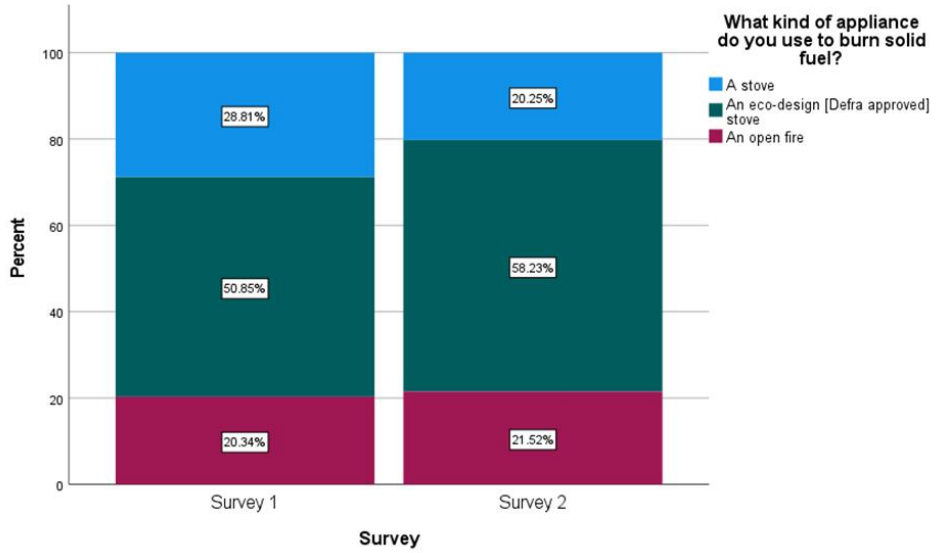


Figure 26: Types of appliances used to burn solid fuel

The mean frequency of burning during wintertime (Q7) is variable with 70% in Survey 1 and 60% in Survey 2 stating that they burn solid fuel once a week or more (Figure 27). The reduction in frequency is not statistically significant but maybe a reflection of the mild weather around the time of Survey 2. There is no dominant reason why people burn solid fuel (Q8) although the findings resonate with the findings of the KANTAR, 2020 study (Figure 28). In addition to making the dwelling cozy (22% - 25%), other responses include concerns over gas prices and gas use, perception of the practice being more carbon neutral / environmentally friendly and a more focused heat source (i.e. only needing to heat one room).

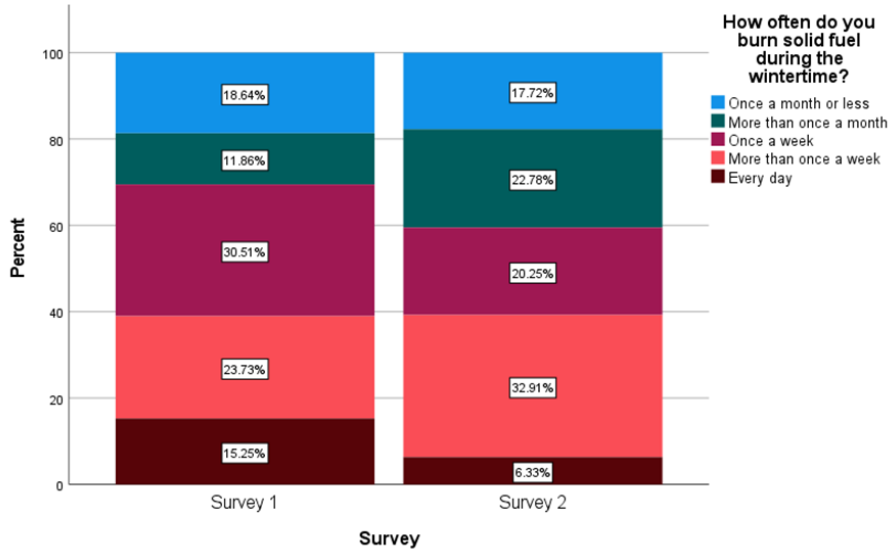


Figure 27: Frequency of solid fuel burning in wintertime (data from Survey 1)

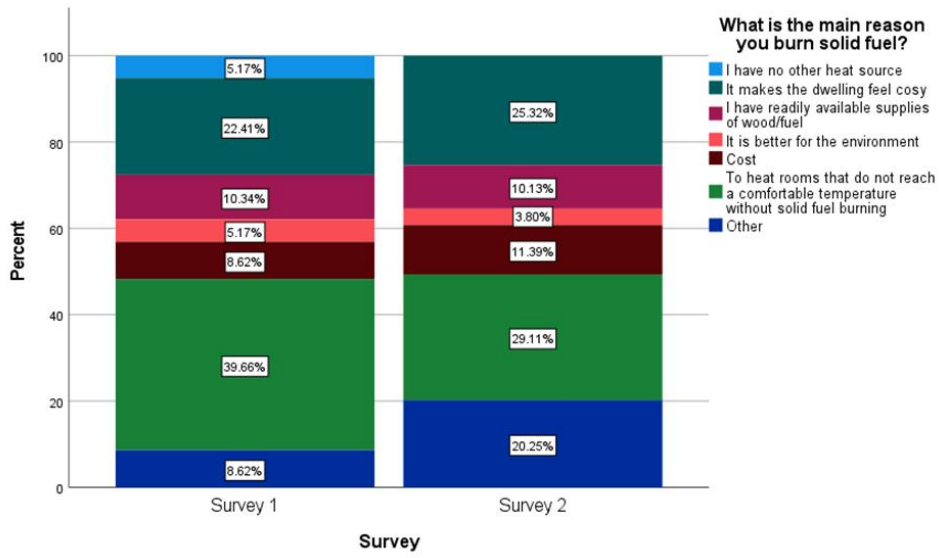


Figure 28: Main reasons for burning solid fuel (data from Survey 1)

Action for reducing pollution

This section explores the participants response to questions related to:

- the reduction of pollution from solid fuel burning (Q12); and
- the most effective way of reducing pollution from solid fuel (Q13).

A summary and description of the findings are provided below.

Most respondents stated that they want action taken to reduce air pollution from solid fuel burning (59% - 79% - Figure 29), however, it is notable that a statistically significant proportion ($p<0.001$) of respondents who did not own a solid fuel fire / stove stated that they wanted action taken (Figure 30). The preferred actions, many of which link back to those in the UK Clean Air Strategy, were focussed on cleaner fuels and better regulation (Figure 31). Other actions supported by some respondents include:

- Better education - "*I don't mind my neighbours running a stove but education should be mandatory - a user licence would ensure best practice and could be withdrawn if the user is causing a nuisance."*
- Greater incentives - *"More incentive, funding and education required to move away from burning fossil fuels to heat homes with clean energy sources."*
- Greater understanding of regulations - *"It would've been helpful to know the rules for domestic solid fuel burning currently are"*

2. More information on fuel types - "*There is not enough differentiation between the effects of burning specific types of solid fuel."*
3. Ban on fuels and burning - "*Just stop selling coal inner city and use Defra Approved burners only for eco wood products. Or ban fires in the city outright."*
4. Correct fuel and technology - "*Correctly seasoned wood and a modern stove is far less polluting"*

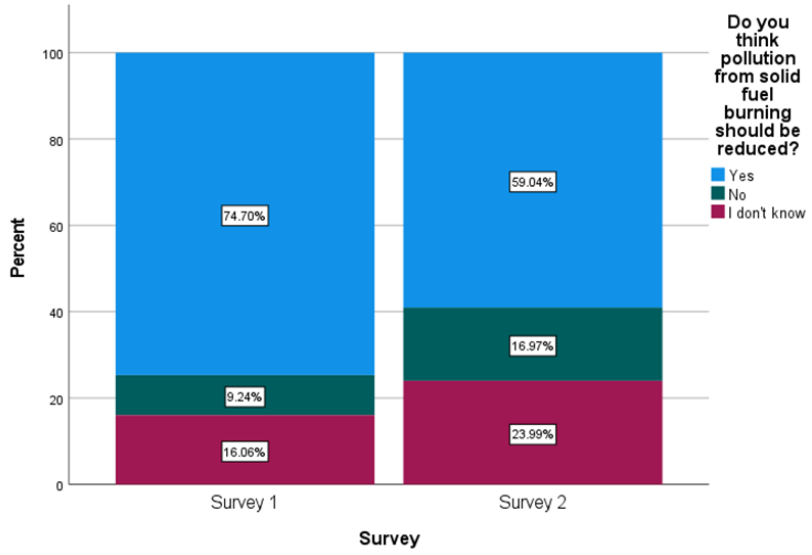


Figure 29: Should pollution from solid fuel burning be reduced?

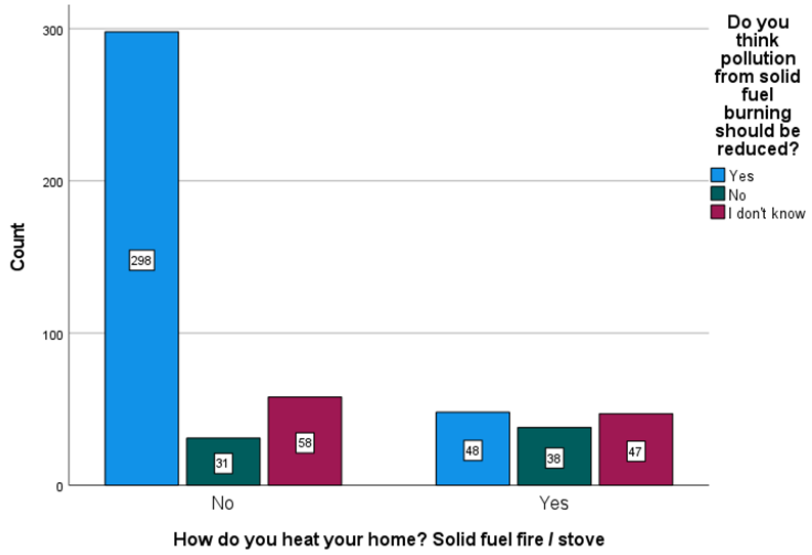


Figure 30: Should pollution from solid fuel burning be reduced based how participants heat their home

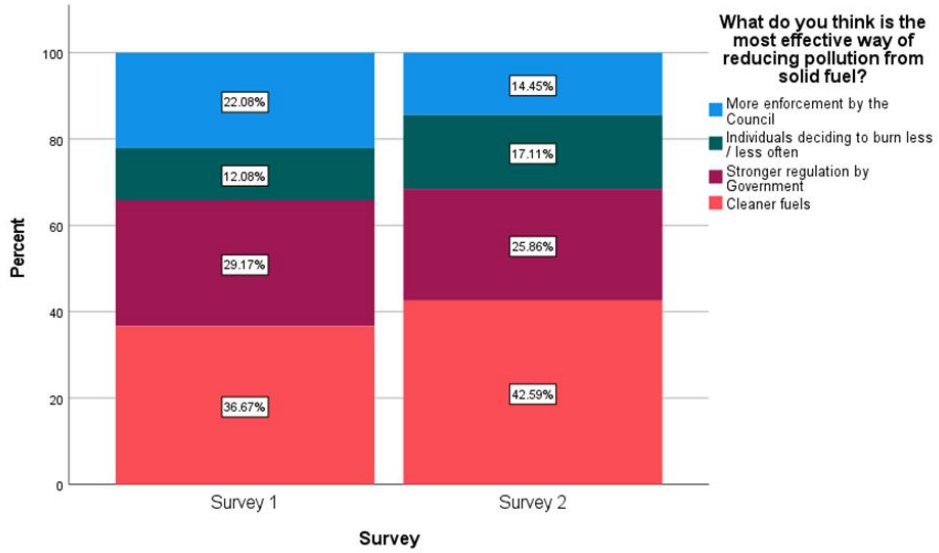


Figure 31: What is the most effective way of reducing pollution from solid fuel burning

Spatial Analysis: Solid Fuel v Indices Multiple Deprivation

The postcodes provided by the respondents in both surveys were cross-tabulated with Indices of Deprivation to determine if a relationship existed between deprivation and solid-fuel use. The data was spatially joined using QGIS. The Indices of Deprivation Deciles (IMD Decile) were grouped:

1. IMD Decile 1-3 = Group 1 (most deprived)
2. IMD Decile 4-6 = Group 2
3. IMD Decile 7-10 = Group 3 (least deprived)

Analysis found that there was no statistical relationship between deprivation and solid fuel burning although it was notable that 86% of those that use solid fuel are in the higher IMD_Groups 2 and 3 i.e. least deprived (Figure 32). This may reflect the growing use of solid fuel burning in least deprived communities or may reflect the background of respondents that complete surveys and engage in project like Slow the Smoke.

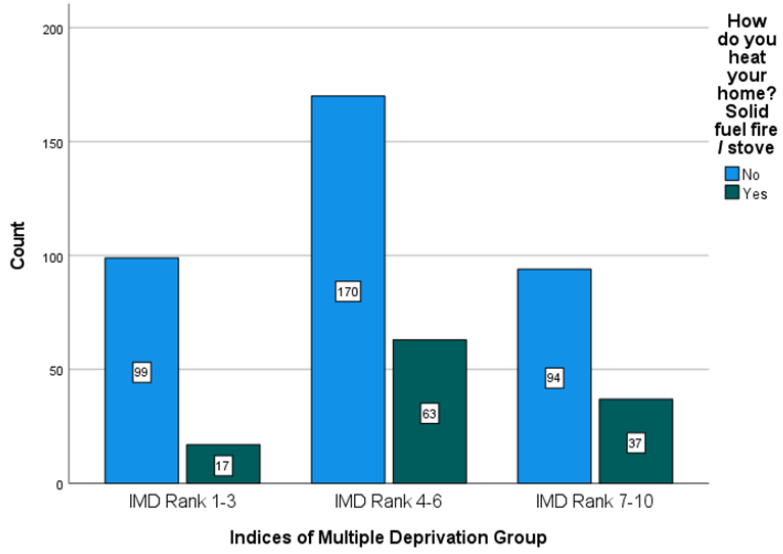


Figure 32: Relationship between solid fuel burning and deprivation

Impact of the Slow the Smoke initiative

This section explores the participants response to questions related to:

- their awareness of the Slow the Smoke Initiative (Q14); and
- how the initiative has impacted their knowledge (Q15). A summary and description of the findings are provided below.

These questions were only asked in Survey 2.

Approximately, 18% of respondents stated that they were aware of the Slow the Smoke initiative. Of those that stated they were aware of the initiative 45% stated that it improved their knowledge of air pollution in general; 51% stated this is raised their understanding of the impact of solid fuel burning on local air quality; 18% felt more knowledgeable about ways to reduce air pollution from solid fuel burning; and 10% thought there were more empowered to encourage others to reduce air pollution from solid fuel burning.

5 Quantitative analysis of low-cost sensor data

The following section provides an overview of the equipment used and an analysis of two co-location studies and a temporal / spatial analysis of the data collected.

Monitoring equipment and data access

Monitoring used a combination of an equivalence particulate matter monitor (BAM), a meteorological station measuring wind speed and direction, temperature and humidity and citizen built Sensor.Community particulate sensors. By using both reference/equivalence data combined with low-cost sensors it was possible to check the quality of the data being produced by the low cost sensors and cover a larger area of the city in an attempt to identify local patterns of pollution potentially linked to solid fuel use. The Bristol City Council Open Data Portal was used to set up a dashboard where real time data can be accessed by the public and interpretation of the data presented. All datasets are open access following the FAIR principles of data access.

1. **Continuous Analysers**: The BAM 1020 data are available through the air-quality-data-continuous datasets.
2. **Co-located Sensor.Community sensors**
    a. The Parson Street Sensor.Community data are available through the Sensor.Community dataset
    b. For the Temple Way sensor, it was not possible to register this on the Sensor.Community website. A different approach was developed to retrieve the data, which is available through the Madavi API as a combination of csv and zip files. Custom functions were written in R to access these files and import the data as data frames.
3. **Citizen Science Sensor.Community Sensors**: The Sensor.Community data can be access through the Sensor.Community archive focussed on Bristol. In addition, data are aggregated to give an hourly mean value for both PM_{10} and $PM_{2.5}$.

Co-location studies at Parson Street and Temple Way

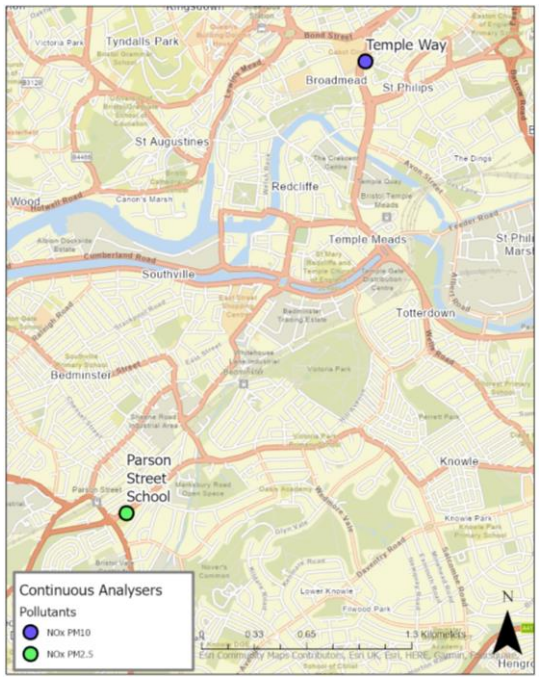
The aim of the colocation study was to compare the performance of the low cost sensors (airrohr SDS011 fine dust sensors aka Sensor.Community) with the performance of reference method instruments measuring the same pollutant. The method of implementing this comparison was to collect data for the two co-located devices and establish the linearity of the response using a linear model to report coefficients and R^2 values. Within this study it was not possible to compare the responses of multiple low-cost sensors with each other as there was not a budget to purchase additional devices for this purpose.

There are three monitoring sites which measure PM in Bristol. Two of these, Parson Street and Temple Way were used for the colocation study (Table 9). Both sites are operated by the Council allowing for immediate access. Using the AURN St Pauls site would have required permission from the Environment Agency which would have been a time consuming and uncertain process. The equipment used in this colocation study is the Met One BAM 1020 Continuous Particulate Monitor, hereafter referred to as “BAM 1020”. The instrument works by drawing a sample of air through a filter tape every hour. The deposited PM is then exposed to a source of radio-active Carbon 14 on one side of the filter tape. A beta radiation detector is on the other side of the tape and measures the attenuation of the beta radiation through the sampled filter. The attenuation of the beta radiation is a function of the deposited PM mass on the filter tape. Because the flow rate of the sampled air is known, the concentration ($\mu g/m^3$) can be calculated. Hourly concentrations are recorded, either on an internal or external data logger. These data are regularly polled by a central telemetry system.

The Sensor.Community sensors require a wifi signal to push data to a server. The Bristol City Council sites did have wifi available as telemetry at these locations was a combination of 3G modems and analogue land lines. To accommodate the co-location study and for the purposes of virtualising the data collection machine, Teltonika RUT950 4G LTE routers were installed at all the Council monitoring sites. This enabled 4G TCP/IP access to the data loggers or instruments at all the sites and provided a wifi hotspot to enable the Sensor.Community to send data.

The physical installation of the Sensor.Community sensors at both sites was completed in early May 2022. The Sensor.Community were co-located inside the cages of the monitoring sites. Parson Street was installed on 29th March 2022 and Temple Way was installed on 1st May 2022. Analysis of the monitoring data was done using the Openair Package in R.

Table 9: Map and description of the monitoring sites used for the co-location study

	The Temple Way roadside monitoring station is beside a multi-lane section of the A4044, a major route in and out of Bristol city centre. Classed as an urban traffic site, Temple Way measures NO_2 and PM_{10} and has been operational since 2017. The site is affiliated to the national monitoring network.
	The Parson Street School monitoring site has been operating since 2002 and is close to the roadside of a busy, queuing road and represents exposure of schoolchildren and school staff. In recognition of the need to understand exposure to $PM_{2.5}$ at a roadside site the monitoring station was updated with a BAM 1020 in 2021. The site is classified as urban traffic and measures NO_2 and $PM_{2.5}$.

Summary Plots

The summary plots provide simple statistics for the datasets. It is apparent that the reported concentrations from the reference method instruments are generally higher than for the Sensor.Community sensors. It is also clear that the distributions of the concentrations are markedly different, with the Sensor.Community sensors exhibiting a right–skewed distribution compared to the more normally distributed concentrations for the reference method instruments (Figure 33 and Figure 34).

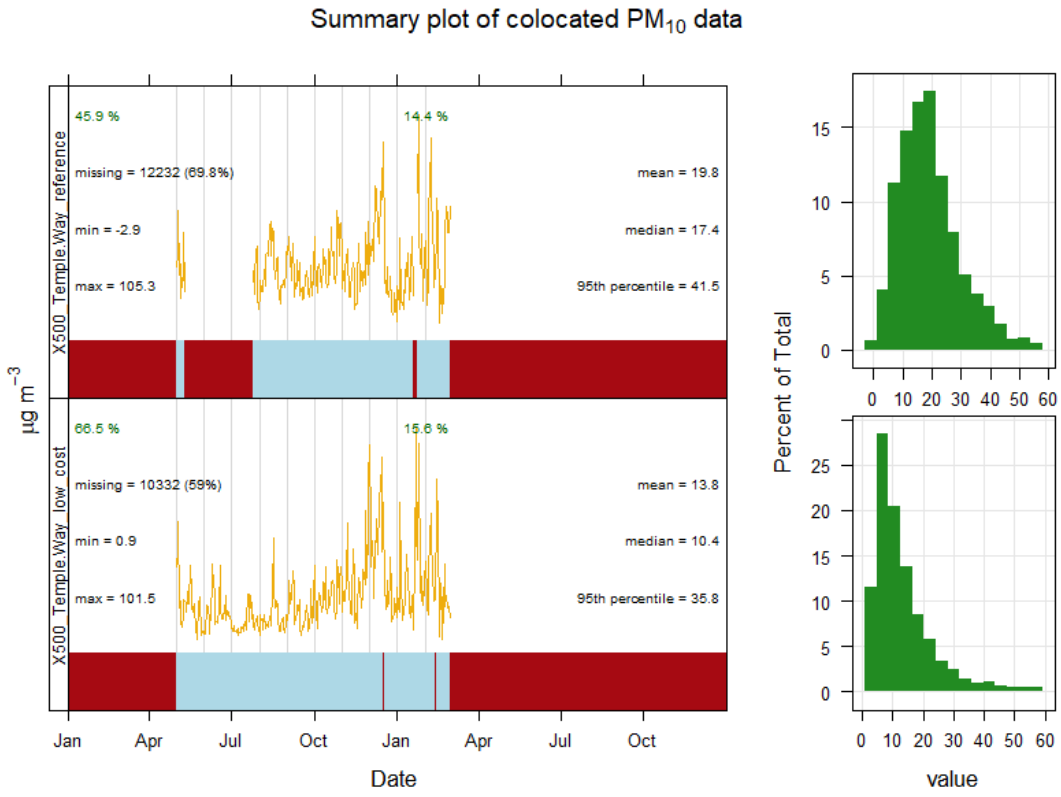


Figure 33: Summary plot of Temple Way reference station and the co-located Sensor.Community sensor

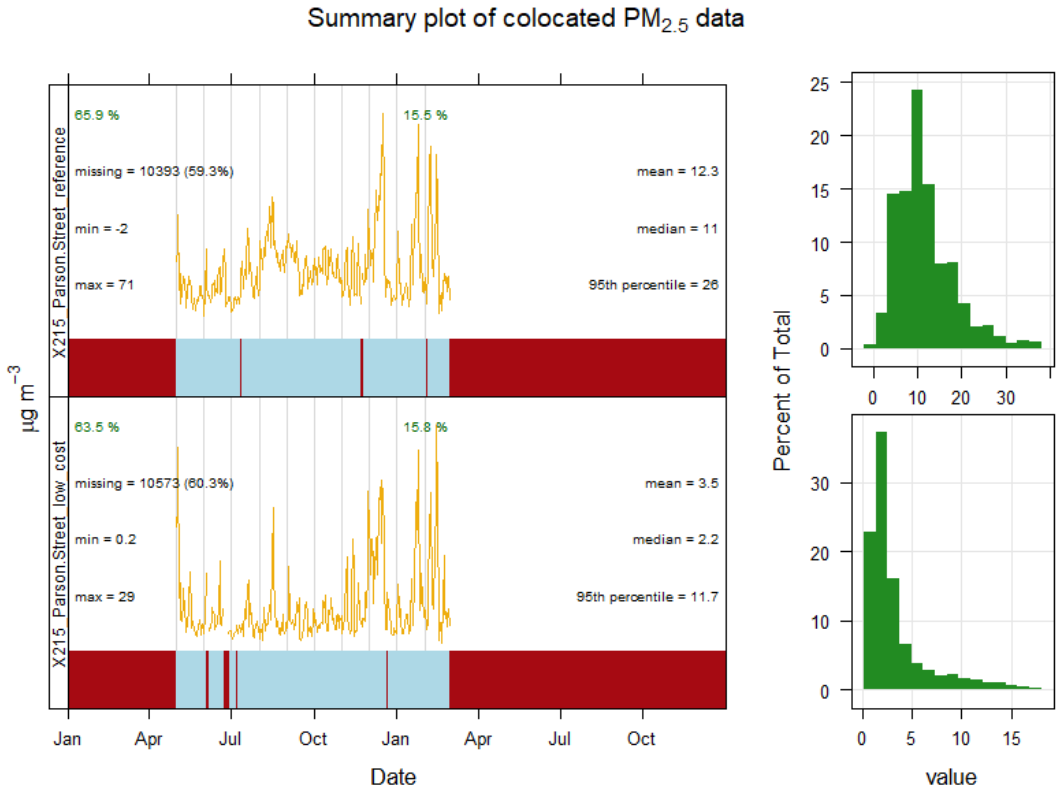


Figure 34: Summary plot of Parson Street reference station and the co-located Sensor.Community sensor

Time Series Analysis

Plotting the time series for each instrument on a single panel further illustrates the disparity in concentrations. Please note, this is not comparing site to site but different instruments at each site. Figure 35 shows that reference method daily concentrations for $PM_{2.5}$ at Parson Street are consistently higher than for the low – cost sensor. The difference in concentrations is not as pronounced for Temple Way but is still significant.

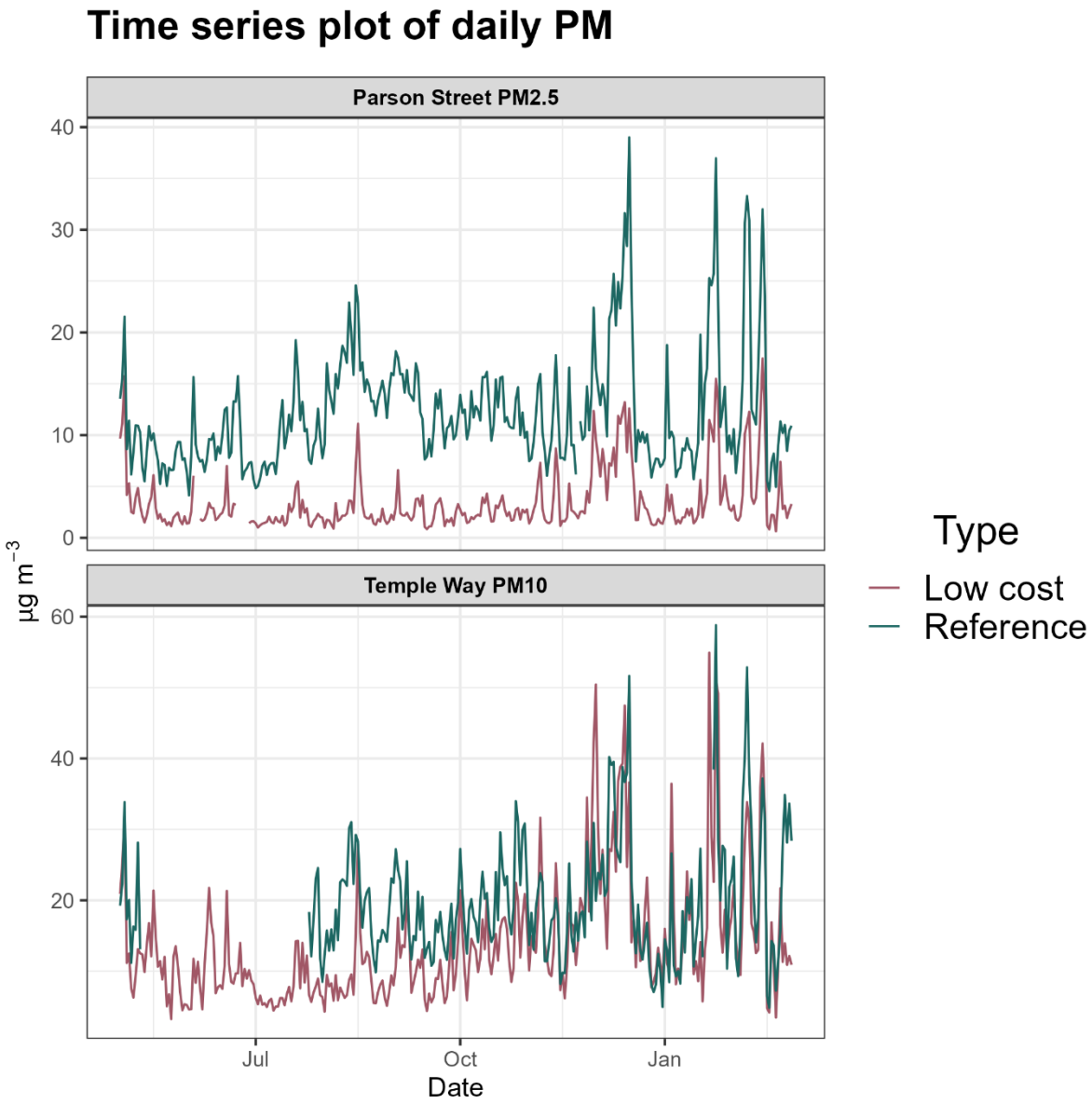


Figure 35: Time series plot of daily PM at the two co-location sites

Examination of sensor drift

The performance of the Sensor.Community sensors relative to the reference method instruments can be further assessed by examining the drift between the two instruments over time. The two charts below show the smoothed drift over time for each co-located site (Figure 36). Smoothing was implemented using the default generalised additive model (gam) option in the R package ggplot2. The patterns of drift at each site are not consistent, but the Sensor.Community devices under–read concentrations for almost all of the measurement period.

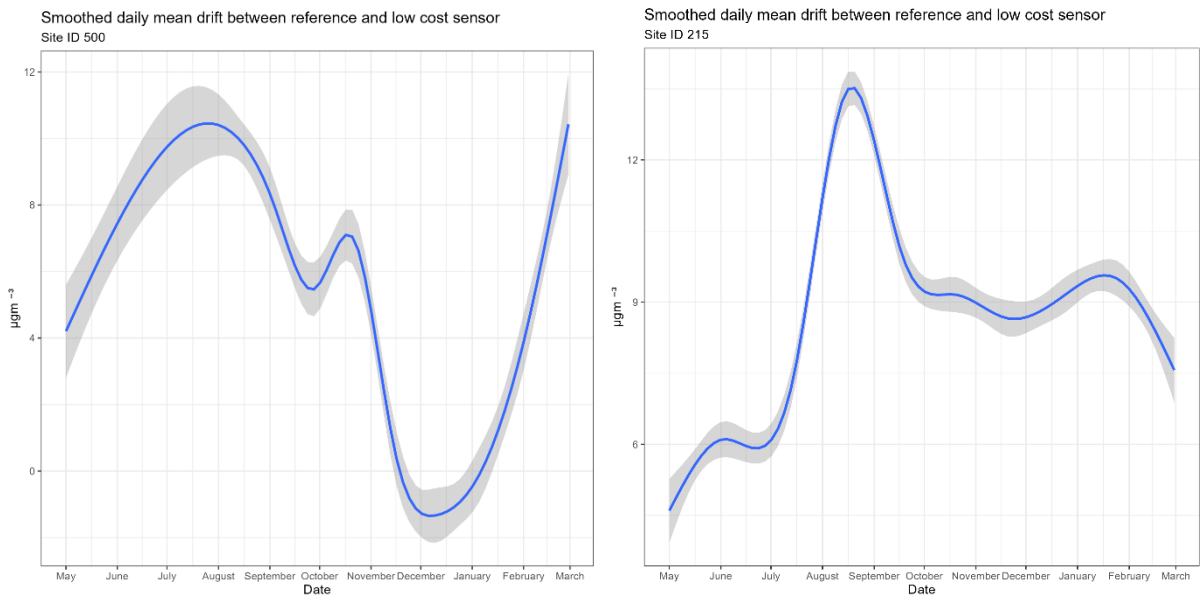


Figure 36: Smoothed daily sensor drift for Temple Way (left) and Parson Street (right) co-located study

Linear Regression

If it is assumed that the concentrations from each type of instrument should relate to each other in a linear fashion, a linear regression can determine the "goodness of fit" between the performance of the devices. After appropriate transformations, a linear regression was conducted on daily data from each co–located site (Figure 37). The analysis was done using the lm() function in R. The scatter plots below show the relationship between the data points for each daily reading and summarise the linear relationship between the low–cost and reference signals.

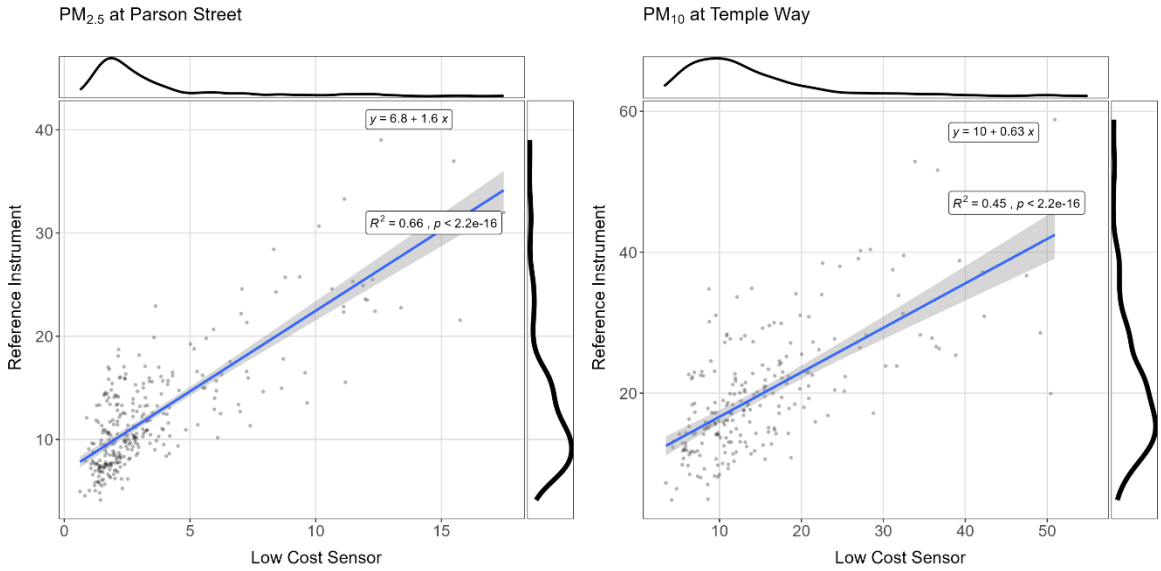


Figure 37: Scatter plot and linear regression of PM2.5 for Parson Street (left) and PM10 for Temple Way (right)

Further analysis was conducted on data from the co–located instruments to develop a statistical model which more accurately predicted the reference data from the low cost instrument data. The full analysis is beyond the scope of this report, but in summary it was found that including humidity as a term in a linear regression model significantly improved the performance of the model. This

simple modelling approach could offer improvements in representing measurements from low–cost sensors in the context of citizen science projects.

Based on the analysis of the co-location studies it can be concluded that:

- The data from low-cost sensors are effective from a public engagement and awareness raising perspective in a citizen science context but not for regulatory purposes.
- This model of sensor (with minimal signal \ post processing) diverges significantly from reference method devices in time, and inconsistently by location and pollutant (drift). Generally, they are under–reading compared to reference methods, which could be unhelpful when trying to communicate the seriousness of the issue.
- Bristol City Council has published a guide for users of these devices setting out their limitations and appropriate uses.
- Other sensors, based on this approach (light scattering) incorporate significant and advanced calibrations in the form of machine learning algorithms. This isn't something the project could include, but Bristol City Council has assessed performance with a simple linear regression approach which could be a pragmatic and low–effort solution to improving sensor performance in this context.
- The technology is likely to improve, which could lead to better understanding of air quality for citizens. This may, in turn, lead to greater pressure for action to improve air quality.

Temporal / Spatial Analysis of the Citizen Science Sensor. Community Data

The sensors are operated by citizen scientists and therefore the data capture rates cannot be expected to match those needed for regulatory purposes. The data capture statistics for each sensor are shown in (Table 10). Figure 38 shown below illustrates the pattern of data collection for each of the sensors deployed in the project.

Table 10: Data capture percentage for each Sensor.Community sensor

Sensor ID	Data Capture (%)
66970	95.1
66972	90.1
66979	86
66966	84.3
66987	72.8
67665	67.9
66974	59.7
67655	59.1
66963	34.1
67568	18

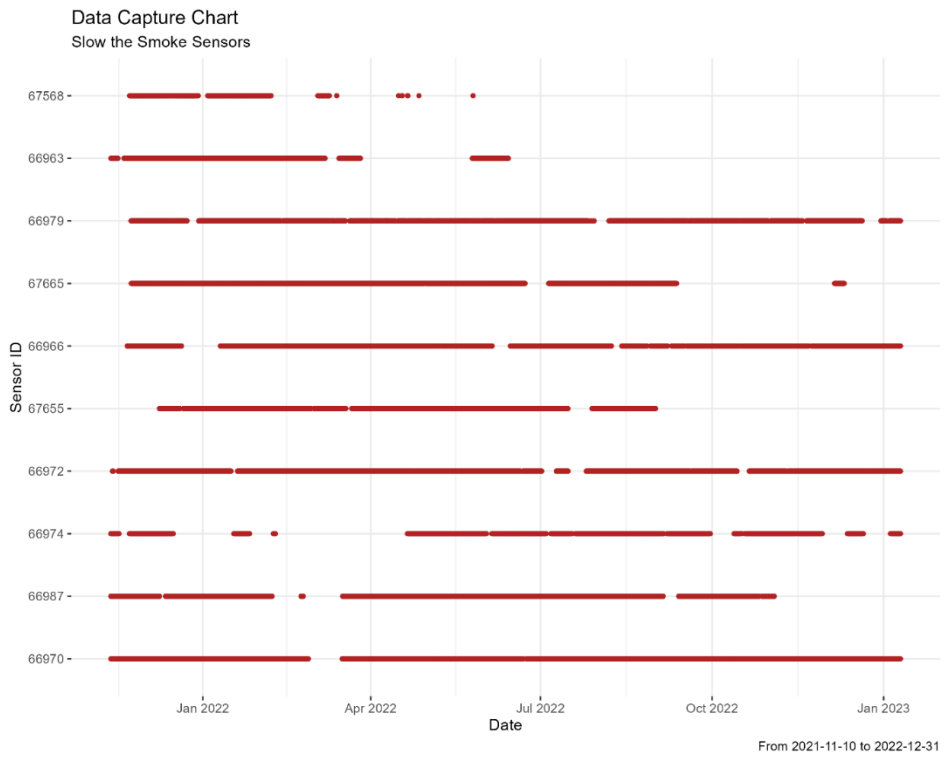


Figure 38: Pattern of data collection for each of the Sensor.Community sensors deployed.

Because the sensors all have a latitude and longitude, as well as values for PM_{10} and $PM_{2.5}$ it is possible to create polar plots of the data using the polarmaps function in the Openair R package. This produces polar plots, overlaid onto an interactive Leaflet map. This is a powerful tool that can be used to interrogate the data to discern patterns of pollution which arise at certain times. The pollution data are "cut" by season and time of day using the cutData function. This enables interactive selection of the combination of season and time of day to show the wind speed and direction when pollution levels are highest. The sensor data was joined to meteorological data from Bristol Lulsgate to derive a wind speed and wind direction for each hour. An interactive version of this map was made available for citizens to 'play' with the data[15].

The example plot shown below (Figure 39) gives polar plots for all sensors in Bristol (not just Slow the Smoke sensors) where data capture exceeded 85%. Robust data capture rates are needed otherwise the algorithm cannot compute a surface for the polar plot. The winter evening example map shown is where the highest levels of $PM_{2.5}$ are observed. This may indicate that solid fuel burning is a potential source. However, dispersion is likely to be low at this time and that may be the dominant factor. The polar plots do indicate that low wind speeds from the east are associated with higher levels of $PM_{2.5}$ than other combinations of wind speed and direction.

[15] https://stevecrawshaw.quarto.pub/slow-the-smoke-polar-maps/

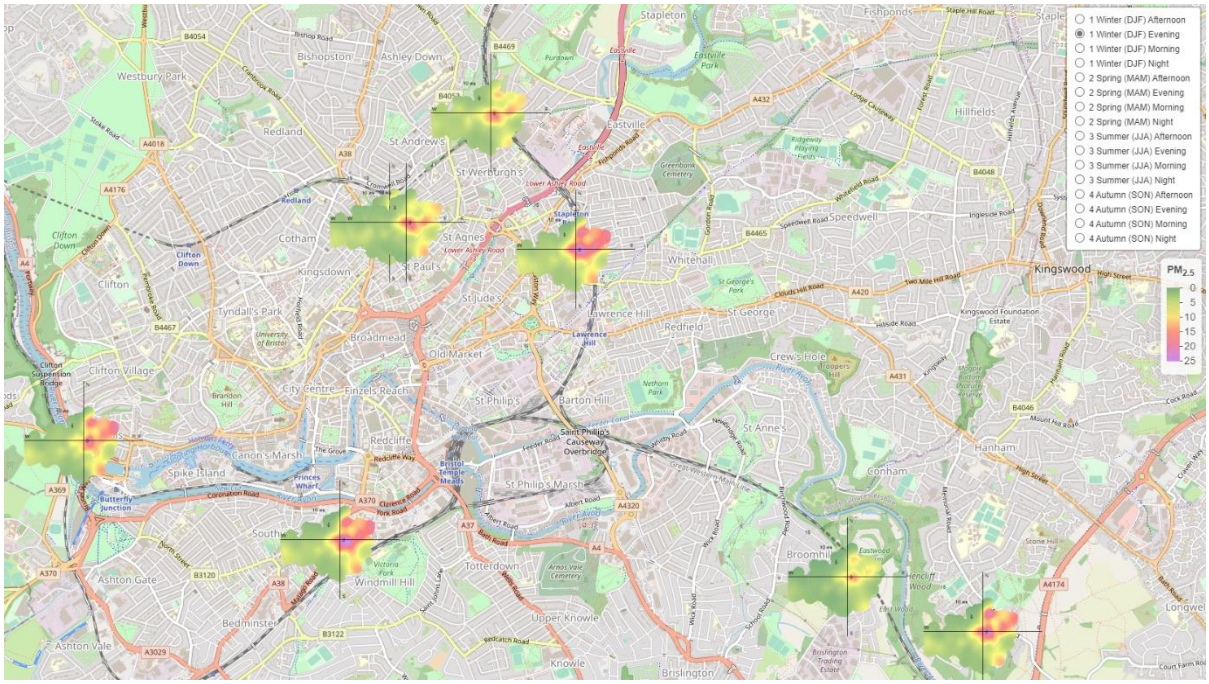


Figure 39: Example of interactive polar plot of PM sensor data in Bristol.

The temporal variation in pollutant concentrations can be plotted using the timeVariation function in the openair R package. The most complete dataset from the Slow the Smoke sensors is from sensor ID 66970, and this sensor's data was analysed and plotted in the chart below (Figure 40). There does seem to be a signal showing elevated concentrations in the evening \ night-time hours, and this is more pronounced at later weekdays and weekends. January and March of 2022 show elevated levels of PM, but February was lower than either January or March. This is likely due to a very stormy February in 2022 when there were three strong storms during mid–February. Autumn and winter months show the highest concentrations. It was not possible, or even desirable, to identify specific individual sources of pollution for each sensor. It is likely that on winter nights there will be several solid fuel burning sources in the study area, and due to complex dispersion patterns, particularly at low wind speeds, the polar plot approach would be unable to yield useful information about sources. Nonetheless we know from national studies that solid fuel burning is an important source of PM and one that is to some degree within the control of local authorities.

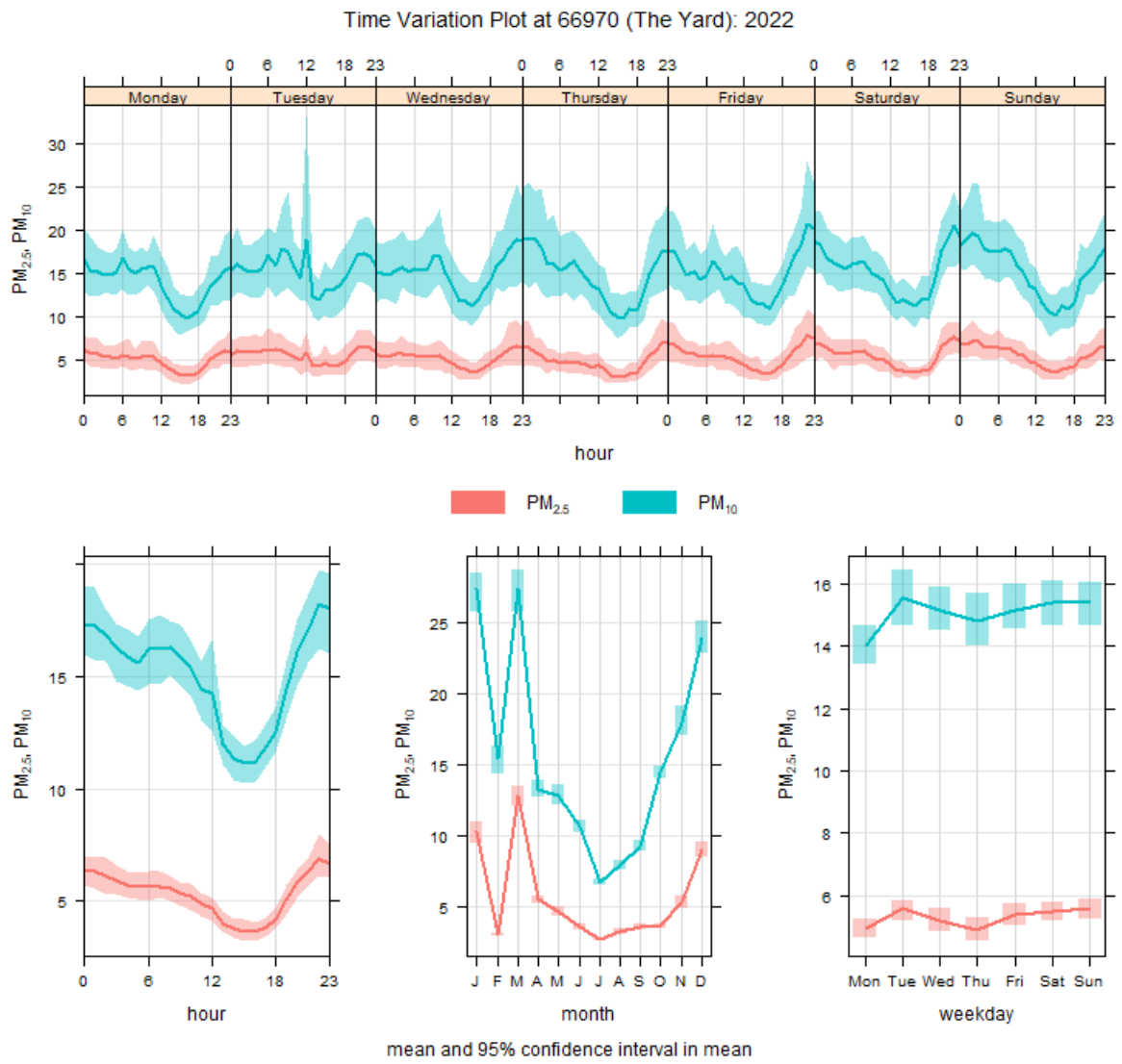


Figure 40: Time variation of PM data from Sensor.Community sensor ID 66970

To further investigate the local contribution of particulate matter, a series of time variation plots were run on "differenced" $PM_{2.5}$ datasets. The approach is to subtract the background concentrations (derived from a rural background site in the vicinity) from a suitable representative urban background site. For this work, the Bristol St. Pauls AURN site was used as the urban background site, and Chilbolton (near Andover) was used as the rural background site. The Sensor.Community sensors were not used because, as they tend to under read, the effect of local contributions would be unduly attenuated in the plots. Using AURN data provides a reasonable level of assurance that the data are comparable, therefore, the Bristol St. Paul's site was used as it is in Ashley ward.

Four plots were produced for each calendar year from 2019 to 2022. The data were conditioned by season, to draw out features that might indicate specific sources, for example emissions from domestic burning on winter evenings. Three plots are shown below, from 2019 2021 and 2022 (Figure 41, Figure 42 and Figure 43). In 2019 an interesting signal can be seen on Saturdays in summer and autumn. This may be outdoor leisure cooking, such as barbecues. In 2021, Thursday evenings in the winter seem to have a peak of locally contributed $PM_{2.5}$. Wednesday and Thursday evenings in winter of 2022 also show higher levels of local PM2.5 than other periods.

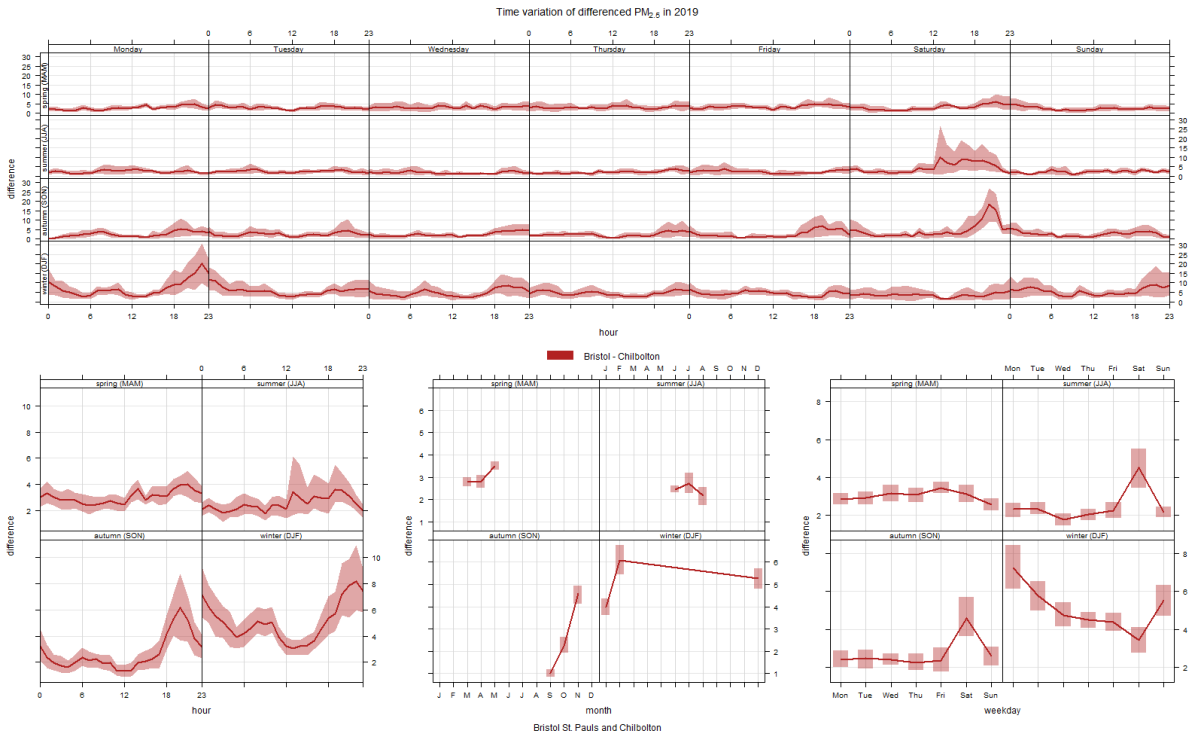


Figure 41: Time variation of differenced PM concentrations in 2019

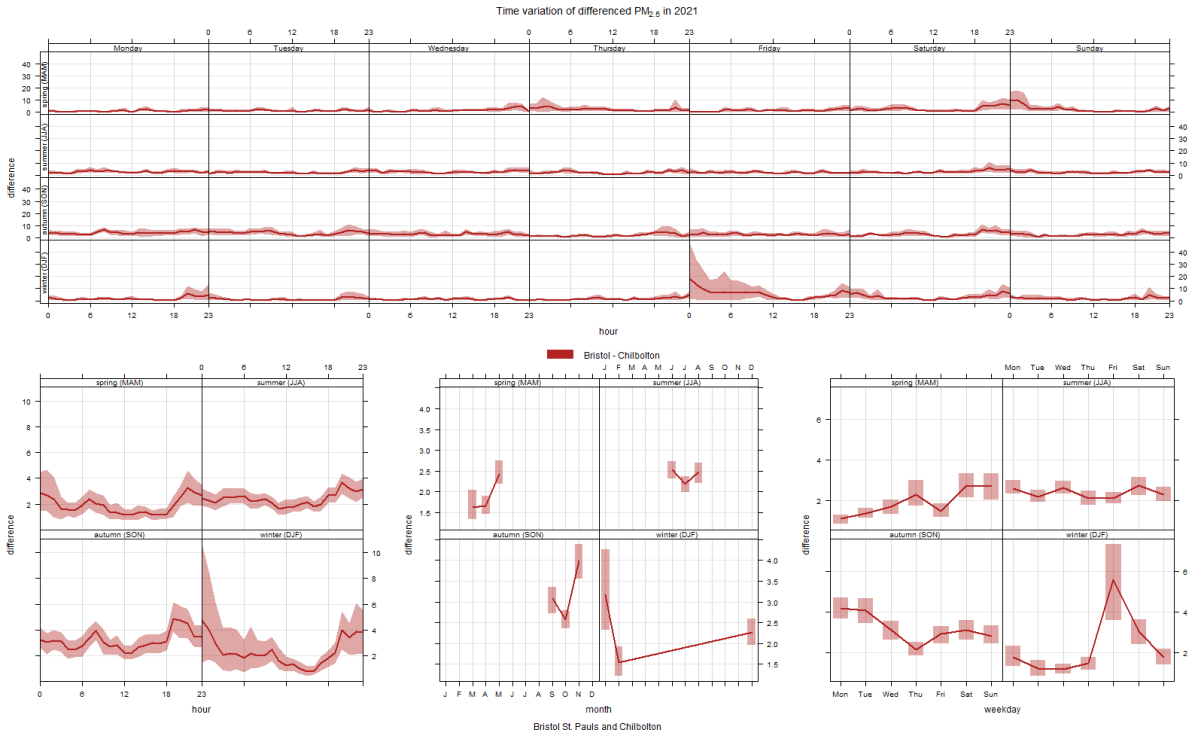


Figure 42: Time variation of differenced PM concentrations in 2021

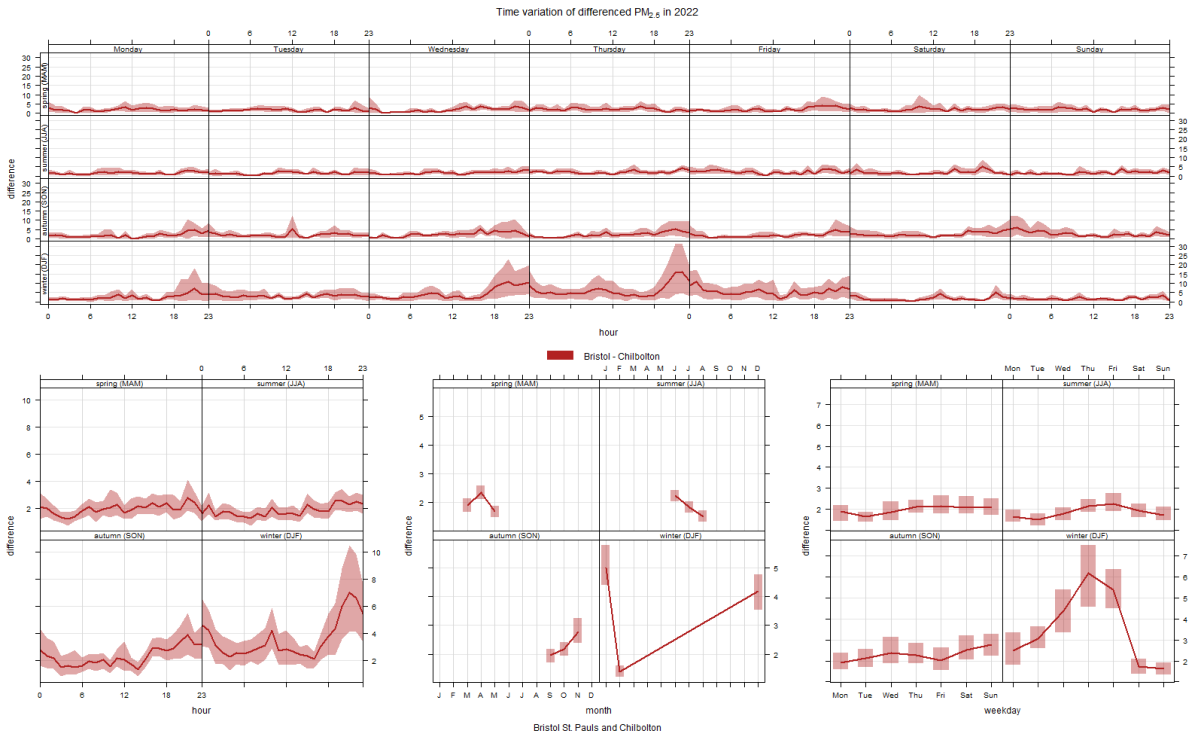


Figure 43: Time variation of differenced PM concentrations in 2022

St Werburgh's reference station

Unfortunately, it was not possible to install the reference station in the study area (Ashley Ward) during 2022 due to various technical delays. Electrical supply has been run, and the concrete plinth for the enclosure is complete. The station will be installed in 2023 and the data reported via Bristol City Councils website.

6 Upscaling the Slow the Smoke intervention

Based on the findings and observations of the Slow the Smoke project several recommendations can be made allow the project to upscale from a pilot study to a larger city-wide initiative. The JRC Scaling up Citizen Science report[16] was used a framework to benchmark our experience and explore specific factors to improve the initiatives reach and how to leverage them. The framework identifies three themes with sub-factors for scaling citizen science projects.

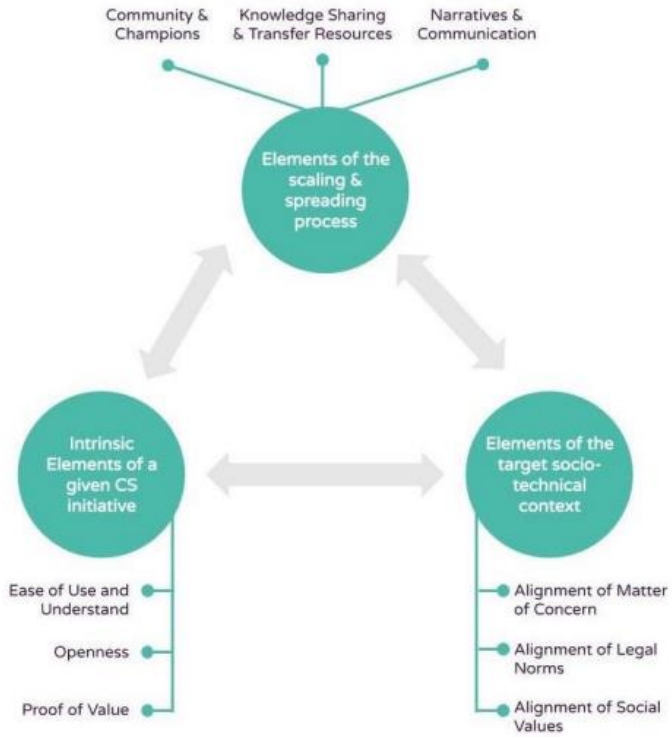


Figure 44: A framework of enabling factors for scaling in citizen science (ref Maccani et al., 2020)

Elements intrinsic to the initiative

Proof of value

For an initiative to be considered valuable, its impact needs to measurable, understandable and observable. Demonstrating reach and impact from citizen science interventions is challenging and this project did not have a clearly defined and embedded Monitoring and Evaluation process due to the scale of the pilot and resource restrictions. However, there are several conclusions that can be reached based on the results from the Slow the Smoke project.

- All activities very well received by the participants. The variety of engagement mechanisms from traditional workshops to innovative sonification and Minecraft resulted in a wider reach to different demographics.
- The Slow the Smoke survey indicated some concerns that *"that wood burners are bad without the whole picture being considered"*. Future activities need to ensure suitable educational and awareness raising are embedded and carefully balance any engagement with a wider understanding of the living challenges that people face (e.g. cost of living).
- The long-term impact on air quality emissions and concentrations is difficult to quantify but feedback from participants indicated an impact on behaviour change. For example, one

[16] Maccani G., Goossensen M., Righi V., Creus J. and Balestrini M., Scaling up Citizen Science - What are the factors associated with increased reach and how to lever them to achieve impact, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-25157-6, doi:10.2760/00926, JRC122219

respondent stated: "*We are owners of a small wood and used to sell firewood. We also have a wood stove. We have given up both of these now in the light of recent research about the dangers of wood burning inside the home.*"

- It is important to demystify any technology used in the approach. The ease of use for established sensor technology (Sensor.Community), access to data (API) and data analysis tools (Openair) were important and mostly easily accessible and utilised even for non-technical audience.

Openness

Citizen science initiatives strongly promote the use of open access principles. The Slow the Smoke project adhered to this principle through open access to monitoring data, data analysis tools and workshop materials / outcomes. Feedback from respondents suggested a greater desire for more education and knowledge exchange around the issue of solid fuel burning and the wider air quality challenge. This transparency principle is essential for any inclusive public engagement and citizen science activity.

Ease of use and understanding

For an initiative to be considered scalable then the technology and activities should be easy to use, transferrable, adaptable, and easy to understand and accessible for a large audience. The conclusions for the Slow the Smoke project are:

- The subject topic, air pollution, solid fuel burning and health impacts, is scientifically complex but can be easy to communicate and engage the public if you can link it to people's lived experience.
- Any technology used needs to be carefully considered as it may be limitation for some (i.e. need to access wifi).
- Fitting remote power plugs to reference monitors enables the sensors to be remotely powered off and on again, which could help when running another citizen science project.
- There is a very important role and effort required from key experts to explain the data thereby ensuring that there is no accidental or wilful misinterpretation of the data by the citizens.
- The variety of engagement mechanisms are important. Traditional workshop approach is transferrable to other topics but technical workshops (e.g. Sonification and Minecraft) require specific skills and expertise.

Elements that support the scaling process

Narratives and Communication

Any successful initiative will be heavily influenced by the communication and dissemination strategies and the narratives generated around the topic. These strategies are not only important for raising awareness but can also act as an enabler for the uptake of the project. The Slow The Smoke initiative fostered multiple communication and narrative building activities:

- Mass communication (Bristol City Council website, publications) and word of mouth communication is essential to inform and empower citizen advocates to encourage wider community behaviour change. Projects should not rely on self–selection, however tempting that might be, to get the project going. Proactive and targeted recruitment is essential.
- Having the additional support from local Councillors to raise awareness is very helpful but need to be careful that citizens don't feel like the issue is being politicised.
- There is a need to alter narratives and communication approaches for different audiences (children, youth, adults) and adapt materials to consider different ethnicities, genders, ages, disabilities etc

- It is essential to have a legacy plan in place for ongoing access to materials and data post project.

Community and Champions

This considers the alignment of local actors or "an ecosystem of agents" around a common concern to help reenforce and foster continuous engagement. The Slow the Smoke project tried to ensure that all actors/ agents were regularly engaged at key points:

- **Contributors**: All activities were open to any citizen who wanted to participate regardless if they had a Sensor.Community sensor or not. In addition to the ten Sensor.Community hosts, contributors were highly valuable to the project as their insights helped provided context to the air pollution narrative.
- **Users**: The data generated can be used by a range of actors including citizens, local NGOs, Bristol City Council, academics etc. The step to embed the data on the Bristol Data Portal ensured access for all actors but also gave the data a greater sense of legitimacy and robustness.
- **Manager / Orchestrator**: The Project team brought a combination of skills and expertise which provided the citizens with a greater sense of trust in the project and the outcomes. However, there was a sense that Bristol City Council was somewhat compromised in running this project as the natural next step is to build a campaign (i.e. a campaign for Bristol City Council to do something more). It maybe that initiatives like this are best run by a truly independent body.
- **Champion**: Numerous local champions were essential to the reach and uptake of the project e.g. Play Wooden CIC, local citizen advocates etc
- Scaled up projects can evolve and adapt approaches from other projects that offer innovative models for future work (e.g. https://socio-bee.eu/)

Knowledge Sharing and Transfer Resources

This factor considers the role that resources play in sharing and transferring of knowledge. It considers three types of knowledge: (1) Inventories and Catalogues, (2) Best Practice, Education and Training, and (3) Tools, Guidelines and Tutorials. Slow the Smoke achieved this by:

- Basing the project on the Bristol Approach framework which is considered existing best practice for citizen science. By adopting the framework, the Slow the Smoke approach was following a proven methodology.
- Creating workshop information materials including technical guidelines for aspects such as building and installing the Sensor.Community sensor, analysis of the air quality data and the Minecraft activities.

Elements of the target socio-technical context

Alignment to matters of concern

The project and any scaled replication must ensure that it aligns to matters that concern the citizens and the project design is adaptable in nature to allow the citizens to co-design the research questions to what matters to them within the boundaries of the original topic. The Slow the Smoke initiative resonated with people as air pollution is such as well documented issue in Bristol and the UK, with greater media coverage in recent years. However, even within the context of this project it was notable that the discussion around the topic (air pollution) often drifted away from solid fuel burning and back towards road traffic. There are many reasons for this: (a) people recognised traffic as being the dominant source of pollution (see the Survey data); (b) traffic is foremost in the thoughts of Bristol citizens due to the introduction of the Clean Air Zone in November 2022; (c) there is a notable increase in the public connection between traffic, air pollution and their day-to-day behaviours due to initiatives like ClairCity (https://www.claircity.eu/) and the observable impact of

Covid restrictions on personal mobility. Finally, future scaled projects can generate co-benefits by considering the intrinsic links between air pollution and carbon emission / net zero, wider environmental concerns (e.g. noise) and the wider Sustainable Development Goals.

Legal alignment

This reflects the need for any project to ensure that it is compliant with all legal considerations. The Slow the Smoke project is considered low risk in this regard especially as the project ensured full ethical and data project compliance in relation to the survey, anonymity for the citizen scientists and suitable protections and permissions for workshop participants.

Social values alignment

This considers the need to avoid misalignment with social aspects including cultural and language barriers. Slow the Smoke recognised this early in the process as it is part of the principles of the Bristol Approach. For example, translators were provided by the Play Wooden team to support with Somali translation in St Pauls, venues were accessible for all participants, venues and the timing of activities were aligned with family commitments, prayer rooms were made available during workshops etc.

Transferrable lessons for future initiatives

Despite the success of the Slow the Smoke project there are still several transferrable lessons that can help other initiatives to adapt the project approach and/or for Bristol to scale up the initiative across the city. These include:

Citizen Scientists:

- Recruitment of citizen scientist is always challenging but more can be done to attain greater representativity and there is a permanent desire towards greater equality, inclusivity, and diversity. As such, language is very important and the term 'citizen science' is potentially problematic as many communities can feel marginalized it (e.g. undocumented migrants). Community Science or Public Participation in Scientific Research (PPSR) can feel more open and inclusive to all communities.
- Low costs sensors are, by definition, low cost. When considering budget, greater spatial density of the network can be achieved by increasing the number of sensors. However, this also requires greater resources dedicated to support and management of these networks.
- More can be done to empower the citizen scientists to create their own narratives with the data from their own sensors and to be able to talk to others about their findings in a meaningful way.
- More innovation around the technology used may lead to more consistent data capture.

Community Workshops:

- Many people attend these workshops with their own agenda; therefore, the approach need to be flexible to accommodate (or refute) narratives and experiences introduced.
- Plan the workshops with trusted organisations who work in the area as it creates greater trust and uptake resulting in good engagement and enthusiasm from the participants. Word of mouth invitations and social media groups worked very effectively.
- Eventbrite bookings are not necessarily a sign of attendance numbers. Generally, more will book on than will attend.
- Food and beverages are always appreciated by participants.
- It is hard to get a continuous thread of participants to attend workshops through the project, with most only attending one workshop session. Having a website, blog or newsletter sent out to keep people engaged and up to date about the progress is a great way to keep them engaged and enthusiastic about the project, also allowing for more citizen feedback.

- There may be scope for greater social media effort to drive engagement.

Sonification:

- Telling data stories using the sonification technique opens up the participants' understanding of the data on a deep personal level. By experiencing the data through one's senses it is demystified. This gives a person a new position/point of view from which to approach the information.
- Bringing the scientists, musicians and public together to co-create the music was very powerful in building relationships and giving the sense of it being locally created about a local problem to help foster local advocacy for change.
- It is important to test the venue booked for acoustics when performing a piece of music.

Minecraft:

- Delivery through schools and promotion with STEM Clubs can encourage better attendance but technical issues like school firewall issues may limit uptake.
- Minecraft and gamification has a lot of awareness raising and educational potential.
- Team building is very important so a simple physical activity can break down barriers and support the team building design activities.
- Having the map of the exact neighbourhood is an exciting feature and localizes the game for the users.
- Keep it fun!

7. Conclusions

The project aim was to achieve air quality benefits in both the short and long term through the planned monitoring, engagement and awareness raising activities in a pilot area of the city (Ashley Ward which includes the areas of St Werburghs, St Pauls, Ashley, and Montpelier). This aim was partially achieved in that the relationship between solid-fuel burning and air pollution was heightened through a diversity of engagement activities but the longer term benefits of improved air quality cannot yet be determined.

A core strength of the project was the scientific robustness underpinning the approach, yet it contained an inherent flexibility that allowed the project team and participants to be responsive to innovative opportunities (e.g. sonification, Minecraft). Grounded in the Bristol Approach, the pilot citizen science aspect using the Sensor.Community technology was successful and has notable scalable potential. The public surveys provided the Council with a greater understanding of the factors that influence people's behaviour and the variety of workshop approaches proved to be popular with adults and young people.

As a pilot project, the template was successful in promoting a greater understanding of the issues and testing a methodology that is scalable and transferrable. However, this pilot project illustrated the importance of continued and sustained engagement around the challenge going forward.

8 Appendix A

Data Dictionary for Survey 1 and Survey 2

All questions were asked in Survey 1 and Survey 2 except for Questions 11, 14 and 15 which were asked in Survey 2 only.

	Survey 1	Survey 2
Number of Variables	15	18
Number of Cases	256	275

Q1: What do you think is the biggest source of air pollution in your area?

1. Roads
2. Industry
3. Smoke from solid fuel burners
4. Agriculture
5. I don't know
6. Other

Q2: How concerned are you about the effect of air pollution on your, or your family's health?

1. Concerned
2. Neither concerned nor unconcerned
3. Unconcerned

Q3: Thinking about the past five years, do you think air quality where you live has improved or deteriorated?

1. Improved a lot
2. Improved a little
3. No change
4. Deteriorated a little
5. Deteriorated a lot
6. I don't know

Q4: How do you heat your home?

1. None
2. Gas central heating (mains gas)
3. Gas fire (mains gas)
4. Electric heater
5. Gas heating (bottled gas)
6. Heat pump
7. Solid fuel heating / hot water (e.g. back boiler)
8. Solid fuel fire/stove (e.g. wood, smokeless fuel, coal burned inside the house)

Q5: Which types of fuel do you burn?

1. Dry seasoned wood
2. Smokeless fuel
3. Coal
4. Other wood

5. Other

Q6: What kind of appliance do you use to burn solid fuel?

1. A stove
2. An eco-design (Defra approved) stove
3. An open fire

Q7: How often do you burn solid fuel during the wintertime?

1. Once a month or less
2. More than once a month
3. Once a week
4. More than once a week
5. Every day

Q8: What is the main reason you burn solid fuel?

1. I have no other heat source
2. It makes the dwelling feel cosy
3. I have readily available supplies of wood/fuel
4. It's better for the environment
5. Cost
6. To heat rooms that do not reach a comfortable temperature without woodburning
7. Other

Q9: How concerned are you about indoor solid fuel burning in your neighbourhood?

1. Concerned
2. Neither concerned nor unconcerned
3. Unconcerned

Q10: If you are concerned, what is the main reason for this?

1. It smells bad
2. It makes my laundry smell
3. It's bad for my / my family's health
4. It is inconsiderate

Q11: Have you noticed an increase or decrease in solid fuel burning in your neighbourhood since last year?

1. Large increase
2. Small increase
3. No change
4. Small decrease
5. Large decrease

Q12: Do you think pollution from solid fuel burning should be reduced?

1. Yes
2. No
3. I don't know

Q13: What do you think is the most effective way of reducing pollution from solid fuel?

1. More enforcement by the Council
2. Individuals deciding to burn less / less often
3. Stronger regulation by Government
4. Cleaner fuels

Q14: Have you been aware of the Slow the Smoke project in Bristol to raise awareness of solid fuel burning and the impact on air pollution?

1. Yes
2. No

Q15: If yes, has Slow the Smoke improved your knowledge about the following?

1. Air pollution in general
2. Solid fuel and its impact on local air quality
3. How I can reduce air pollution from solid fuel burning in my home
4. How I can encourage other people to reduce air pollution from solid fuel burning

Q16: What is your full postcode?

Q17: Do you own or rent your home?

1. Own (or mortgage)
2. Rent

Q18: What type of home do you live in?

1. House
2. Flat/Apartment
3. Maisonette
4. Bungalow
5. Caravan/Van