COMPAIR

DELIVERABLE

D7.4 Recommendations for new CS tactics in the CS scientific agenda

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List of Abbreviations

Abbreviation	Definition
AR	Augmented Reality
CS	Citizen Science
CO2	Carbon dioxide
DEVA	Dynamic Exposure Visualisation Application
DEV-D	Dynamic Exposure Visualization Dashboard
DIY	Do It Yourself
LCS	Low Cost Sensors
MoRRI	Monitoring the Evolution and Benefits of Responsible Research and Innovation
NO2	Nitrogen Dioxide
PM	Particulate Matter
PMD	Policy Monitoring Dashboard
R&I	Research and Innovation
RRI	Responsible Research and Innovation
SDGs	Sustainable Development Goals
VMM	Vlaamse Milieumaatschappij (Flemish Environment Agency)
WHO	World Health Organization
WP	Work Package

Executive Summary

COMPAIR enables communities to understand the impact of their actions on the environment by actively involving citizens in the collection and analysis of air quality data. Through its seven publications and participation in scientific workshops and conferences, COMPAIR has effectively demonstrated its scientific engagement by presenting innovative dashboards, digital twins and citizen science (CS) tools aimed at tackling air pollution and promoting participatory policy-making. The project has demonstrated how citizen science can be used to raise awareness and empower citizens to take a proactive role in environmental decision-making, ultimately contributing to the wider citizen science agenda.

The main objective of this deliverable is to document scientific engagement activities, including relevant citizen science publications, participation in scientific workshops and conferences. It also aims to recommend citizen science tactics that have emerged from the pilots, contributing to the advancement of the citizen science scientific agenda. To evaluate the impact of its initiatives, COMPAIR has adopted the MoRRI indicators, which focus on assessing the societal, democratic and economic costs and benefits of citizen science. During the project all of the selected MoRRI indicators have been achieved. The CS tactics were applied during the pilots applications and they are assessed using specific MoRRI indicators. Based on this assessment, the lessons learned were derived from the pilots and the engagement strategies developed through each pilot use case.

Pilot case studies have revealed that lessons learned citizen science tactics can increase participation, data quality, behaviour change and overall impact on community engagement and policy making. Key strategies include targeting specific populations, such as seniors, students and lower socioeconomic groups, and simplifying tools to make them more accessible. Regular engagement, technical support and feedback mechanisms are essential to keep participants motivated and overcome challenges. Educational support, including workshops and personalised feedback, has been shown to be crucial in enhancing participants' understanding of complex data and providing more effective contributions.

COMPAIR’s pilots emphasise the importance of community engagement, adaptive communication, and integrating citizen feedback into policy-making. Recognizing enthusiastic participants as local champions, using schools to reach diverse audiences, and fostering collaborative spaces like data cafés are vital for maintaining responsiveness to community needs. The findings highlight the need for technical preparation, ethical considerations and strategic use of citizen-collected data in urban planning. COMPAIR's adaptive approach provides a framework for future citizen science initiatives, ensuring that they are inclusive, impactful and capable of driving sustainable change at the community level. By continuing to engage citizens, COMPAIR is helping to raise environmental awareness and support society's efforts to tackle climate change.

1. Introduction

This deliverable is the result of Task 7.4 of the COMPAIR project and is based on the outcomes of WP5 and WP6. Its purpose is to report on scientific engagement including publications relevant to citizen science, including participation and dissemination in relevant scientific workshops or conferences and to provide recommendations for new citizen science (CS) tactics that emerged from the lessons learned during the pilots, contributing to the citizen science scientific agenda.

COMPAIR has adopted relevant to our project MoRRI indicators (*SLSE 4.2 - Citizen Science activities in RPOs, PE1 - Models of public involvement in Science & Technology decision making, PE2 - Policy-oriented engagement with science, PE3 - Citizen preferences for active participation in S&T decision making, PE10 - National Infrastructure for involvement of citizens and societal actors in R&I*) to assess the impact of its work, specifically focusing on evaluating the societal, democratic, and economic costs and benefits of citizen science. The rest of the MoRRI indicators were deemed irrelevant for the purpose of this deliverable. These indicators were chosen because Responsible Research and Innovation (RRI) aims to align scientific and innovative efforts with societal needs, ensuring benefits for society, the economy, and the scientific community. The MoRRI project indicators offer a robust framework for measuring the evolution of RRI and provide a valuable foundation for policy development and further research (European Commision, 2018). These recommendations for new CS tactics will be based on the MoRRI indicators and the engagement strategies that arose from the pilots' use cases (Athens, Berlin, Flanders, Sofia, Plovdiv).

Throughout the project, different approaches to citizen science activities have been tested, but a crucial component of all pilot activities has been to engage citizens in measurement campaigns that make them aware of their personal exposure to air pollution and climate change, while providing them with tools to visualise the impact of behavioural changes. The aim of this approach is to encourage citizens to adopt behaviours that will benefit their health and the environment, such as a change in transport mode or a reduction in energy consumption. In addition, as shown by at least one pilot activity in COMPAIR (the Herzele school street), involving citizens in these efforts helps them to better understand the rationale behind certain policies, leading to greater public support for these initiatives.

From COMPAIR's achievements across the pilots locations, the project's adaptability and widespread impact has been highlighted along with new citizen science tactics and engagement strategies of vulnerable groups towards more inclusive solutions and decisions. In Athens, the focus was on involving the elderly and lower socioeconomic groups in citizen science to drive behavioural changes, increase awareness of air quality, and promote sustainable lifestyles. In Berlin, the project engaged a community of citizens in both static and dynamic (cycling-based) air quality monitoring campaigns, building a knowledgeable base of volunteers committed to environmental health and sustainable public spaces. In Flanders, the emphasis was on evaluating local policy and educational engagement, particularly among primary school students, which led to the successful implementation of a 'school street' initiative and a 'traffic circulation' plan to enhance safety and air quality. Plovdiv saw a rise in community environmental consciousness through awareness-raising activities on the impact of local traffic on air pollution, with active participation from schools and residents in air quality monitoring. In Sofia, the project engaged elementary school students in workshops to assemble DIY air quality sensors and introduced sustainable transportation solutions, such as school buses, to instil environmental sustainability values from an early age.

Based on the results and the lessons learned of the pilots that have been presented in the WP5 and WP6, the formulation of scientific policy recommendations on how to handle scientific, ethical and cooperative aspects of citizen science for policy making will be drawn up. Special attention will be given to inclusive engagement, how the risks of using CS can be mitigated and how cooperation can be set up with particular attention to expected management and correct scientific interpretation of the outcomes, and how CS activities can be funded. The outcomes of this task will be communicated in WP8.

The rest of the deliverable is structured as follows: Chapter 2 presents a report on scientific engagement by its publications that are relevant to citizen science and participation in scientific workshops or conferences. Chapter 3 presents the analysis framework regarding the four aspects that have emerged (data collection and calibration; ethical issues; actions to reduce emissions; societal issues). Also, it includes the assessment of the MoRRI indicators list during the project. In the fourth chapter, the analysis is carried out regarding the utilisation of the tools in the project, in the context of MoRRI indicators. Finally, in the last chapter recommendations regarding new citizen science tactics are drawn up, based on the lessons learned during the Public Round.

2. Analysis and assessment of citizen science tactics and performance of the solutions metrics

Following the developments of the COMPAIR project and the topics of its research publications, the analysis framework was created regarding 4 aspects: data collection and calibration; ethical issues; actions to reduce emissions (individual and policy related) and societal issues (inclusive participation and collaboration). The following subsections describe these 4 aspects and their sub-indicators (or metrics).

2.1 Data Collection and Calibration

Within the data collection network of official measuring stations, the mobile measurement campaign aimed to fill the data gaps regarding air quality and PM, and to engage citizens to promote new knowledge about air pollution. In this way, citizens were imbued with new knowledge and provided with the proper tools (air quality sensors) to collect important data which, together with the calibration of SODAQ devices by IMEC, could lead to a constructive dialogue with policymakers on the use of citizens' data for public policy purposes. COMPAIR's low-cost sensors aim to provide a wealth of data that are not only waiting to be analysed by the project's researcher and domain experts outside of the project but also by the citizen scientists themselves engaged in COMPAIR.

As mentioned in the deliverable D8.5 CS Lab with MOOC, low-cost sensor (LCS) technology used in citizen science can provide high spatio-temporal resolution measurements that could be used to complement existing datasets from official monitoring stations. However, these LCS require frequent calibration to provide accurate and reliable data as the sensor signal is often affected by environmental conditions, such as temperature and humidity when deployed in the field. The remote calibration method improves the accuracy of the data by deploying the LCS in parallel with reference stations in the field, ensuring that they are of a similar age. The process involves pre-processing the sensor data, selecting a reference station with the highest data similarity and using a multi-linear regression model that incorporates environmental factors, such as temperature and humidity. The calibrated data is then corrected in real time in the cloud.

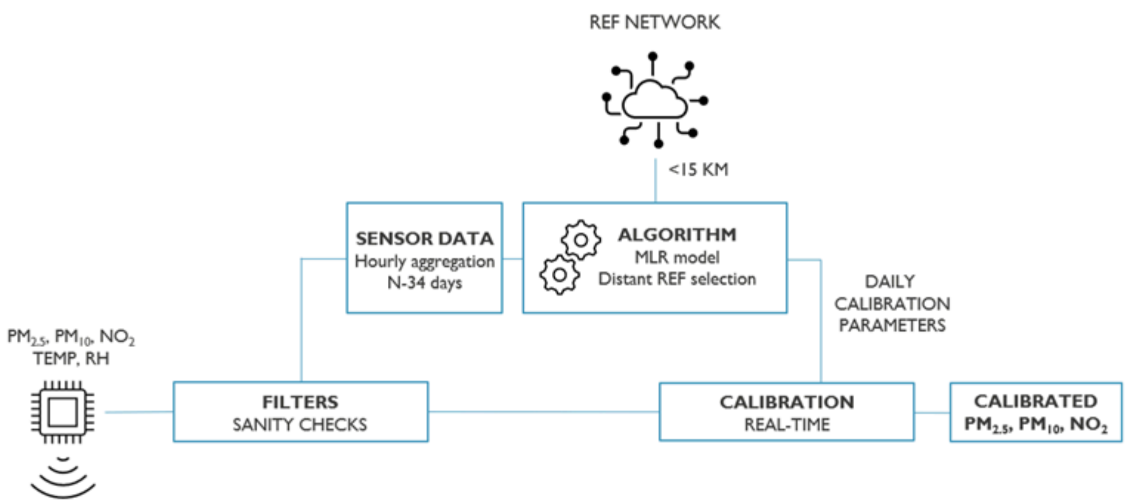

Figure 1 . The cloud-based calibration framework for LCS

In COMPAIR, the plan is to calibrate the data from the SODAQ AIR and OnePlanet NitroSense sensors to minimise these influences (such as sensitivity and drift). To do so, these sensors will be co-located with high-end reference stations and the sensor data acquired during this period will be used to train a calibration algorithm which will be applied to the sensors when deployed in the pilot regions by the citizens. In addition, COMPAIR has extended the remote calibration approach to new geographical areas, including Bulgaria, Greece and Germany. Before COMPAIR, the calibration framework had only been tested in Belgium and the Netherlands. The presence of the other pilots in the project helps to extend the method to new geographical areas. However, the reference stations in the new regions were sparsely distributed, resulting in increased distances between the stations and the

LCS, which posed a risk to calibration performance. In addition, the use of mobile sensors in some of the pilots, such as the Berlin cycling campaign, meant that these sensors also had to be calibrated, even though the framework had originally been developed and tested on static LCS devices. And because the mobile sensors were stored indoors at night, it was not possible to calibrate them at night.

To overcome these challenges, the training data set was selected based on the variability between reference stations, and daytime data were used instead of nighttime data. With these adjustments, it was found that the distant calibration applied to particulate matter measurements resulted in a modest reduction in measurement error. However, this approach was not as effective for other pollutants. Improvements in NO2 (nitrogen dioxide) measurements came only after further changes were made to the model, including reducing the search radius for reference stations in sparsely populated areas.

Two publications on the sensor data and the calibration process are planned by October 2024, one by IMEC on the multi-country sensor calibration mechanism and one by ECSA on the COMPAIR multi-sensor citizen science approach.

2.2 Ethical Aspects

COMPAIR is a research project that puts considerable effort in dealing with the various ethical issues that arose during its implementation. The main reason for this concern is that COMPAIR uses solutions such as sensors, networks, etc to collect data from people and applies CS tactics to help cities and regions get a better air quality by raising the quality of citizen science data, used in decision making.

In order to reach these goals, various tools were designed and developed under the umbrella of the COMPAIR project. Specifically, four tools, namely Policy Monitoring Dashboard (PMD), Carbon Footprint Simulation Dashboard (CO2 Dashboard), Dynamic Exposure Visualisation Dashboard and Dynamic Exposure Visualisation App were used by users/volunteers in various scenarios (see D.3.4 Dashboards Design). These pilot campaigns were designed very carefully, with respect to the ethical recommendations that have already been identified in D.9.1, entitled “H - Requirement No.1” which provides information about ethical requirements that would be met to protect individuals participating in the research.

Specifically, throughout the project, an internal discussion/consultation has been conducted with the research team to ensure that data is collected on a “need to know” basis, i.e. the data is required for a specific purpose that is relevant and limited to the project's objectives. After this process, the aforementioned tools and dashboards were designed and developed for the needs of the project, taking into account privacy by design principles (Articles 5 and 25 of the Regulation (EU) 2016/679 (General Data Protection Regulation); Chapter IV of 'Ethics and data protection', European Commission). We addressed the principle of data minimization, as we included only data that is necessary and proportionate to achieve the project's research objectives. Additionally, the storage of the data was conducted using in-house storage with appropriate security measures (analytically presented in D7.2 Legal

Requirements and Guide to Legal Compliance for Data-Driven Decision Making). Finally, through the consent form and the privacy policy of each tool and of the project in general, participants (natural persons) were informed about and were able to exercise their fundamental rights.

Also, five pilot campaigns were planned (see D2.4 Pilot Operations Plan) in such a way as to respect the rights of natural persons. The project took into account the obligations that data protection imposes regarding the provision of research subjects with detailed information about what would happen to the personal data that each pilot partner would collect. More specifically, for each pilot partner (i.e. Athens, Berlin, Flanders, Plovdiv, and Sofia) a specific consent form was designed, containing the relevant information that would be given to the participants/volunteers. This form contained information about the scope of the project and the research aspects that the collection of their data would contribute to, and information about the project partners and contact details. Additionally, this consent form contained the privacy policy of each tool. Through this text, the volunteers were informed about the personal data being processed, the time of storage of the data, their rights, as well as the security measures that have been put in place.

Finally, it is important to mention that as most of the campaigns involved vulnerable participants (elementary school students, young people, the elderly and minority communities (Roma groups), to name a few) and the research team of the project designed very carefully the process of data collection, requesting only the minimum that were required for the drawing of useful insights for the project. The justification for the involvement of vulnerable participants throughout the campaigns is that one of the project's goals was to raise awareness and to instil environmental sustainability values from an early age (specifically, for the students and young people in general), and also to involve typically underrepresented groups in citizen science (the elderly and minority communities). COMPAIR's strategy to approach these groups of people and to interact with them was to work with organisations that already have established links with these communities, making the communication easier. In this way, the COMPAIR project ensured that none of the participants/volunteers would be stigmatised, re-traumatised or otherwise harmed through their participation in the campaigns.

2.3 Environment (air quality: DEVD, PMD, CO2, DEVA) - Actions to reduce emissions and exposure

While citizen science data in environmental and other fields is increasingly accessible through various public initiatives, its full potential remains untapped due to limited analytical tools and the challenges of cross-domain integration. To unlock the true value of this data, there is a need for advanced yet user-friendly applications that enable individuals to interpret the information, understand its impact on their personal lives, neighbourhoods, cities, and the broader environment, and make informed, fact-based decisions.

COMPAIR’s tools are designed to meet these needs. By aggregating data from multiple sources, they provide a comprehensive view of air pollution and related urban challenges such as traffic, waste management, and energy use. The intuitive, built-in analytics empower users to assess the impact of individual lifestyle choices and government policies on various indicators, including those related to the EU Green Deal, helping users to predict the potential outcomes of specific actions before they are implemented. Additionally, some of the apps utilise Augmented Reality and GPS data to offer personalised insights, making the results more relatable by reflecting users' locations and travel habits.

Furthermore, COMPAIR’s tools serve two different purposes. Policy Monitoring Dashboard (PMD), Dynamic Exposure Visualization Dashboard (DEV-D), Dynamic Exposure Visualisation Application (DEVA), and the first tool of the Carbon Footprint Simulation Dashboard, the Carbon Footprint Calculator, aim to make citizens aware of environmental issues as well as the effects resulting from their daily habits. The second purpose of some of the tools, such as the Policy Monitoring Dashboard (PMD) and the Scenario Simulation Dashboard, the second tool of the Carbon Footprint Simulation Dashboard, is policy-making and citizens' participation in it.

2.3.1 Policy Monitoring Dashboard (PMD)

The Policy Monitoring Dashboard (PMD) is a new visualisation and analysis platform designed to enhance the value of citizen science data. PMD allows users to study the impact of policy measures(e.g. road closures or change in traffic direction,) on traffic and air pollution as part of ex-post policy evaluation. The platform displays data from multiple sources and allows users to drill down into the datasets to gain new insights. PMD supports the monitoring of a target location and surrounding areas to assess whether a policy intervention actually solves the problem or simply moves it further away (the displacement effect).

PMD helps users understand and compare how environmental situations change under different actions. By collecting a large amount of citizen science dat ain a particular setting, the Dashboard will be able to show the impact of different policy implementations on traffic and air quality.

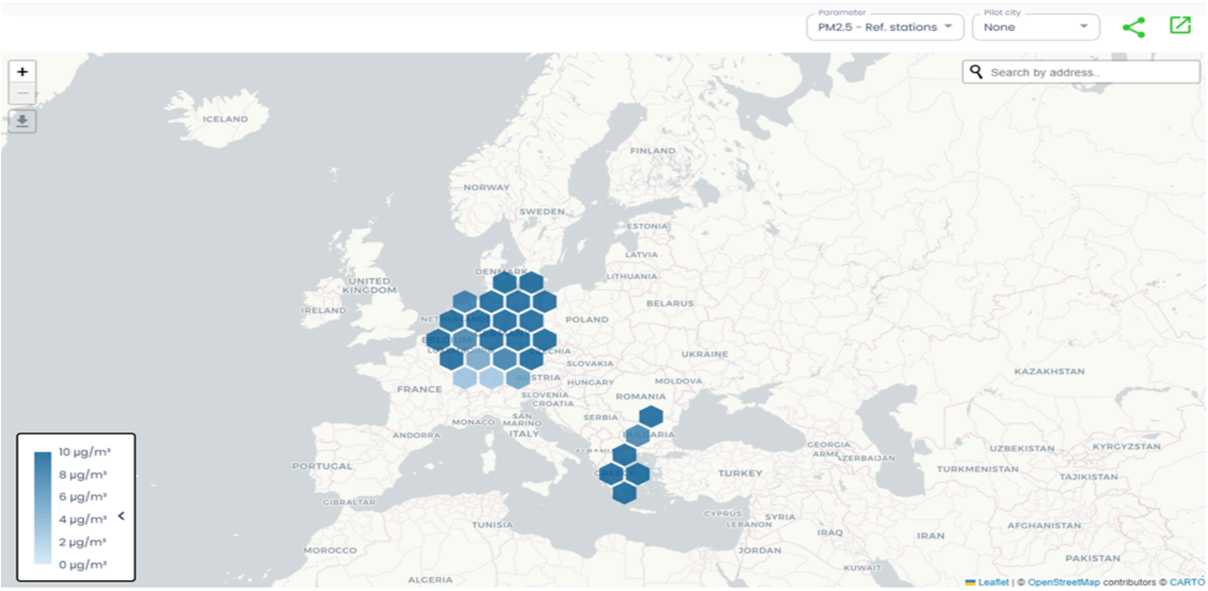

Figure 2 . Policy Monitoring Dashboard (PMD)

2.3.2 Dynamic Exposure Visualization Dashboard (DEV-D)

The Dynamic Exposure Visualization Dashboard (DEV-D) assists users in comprehending and interpreting data gathered from a diverse range of mobile air quality sensors. This tool visualises a combination of geometric information from bicycle and walking trips recorded by the DEVA trip recorder, and air quality data collected by mobile sensors like the SODAQ fine dust sensor measuring PM1.0, 2.5 and 10. The data collected from these devices were visualised and analysed using the Dynamic Exposure Visualisation Dashboard (DEV-D). Users can view colour-coded air quality data along their trips (as well as trips made by others in the vicinity) on a map, allowing for detailed observation of air quality fluctuations.

Furthermore, users can filter the data, visualise the evolution of air quality on a color-coded map and various graphs, measure their exposure or inhaled dose (dynamically adjusted based on activity level, gender, and age) of pollutants and relate data to the WHO-guidelines. Additionally, they can see the detailed evolution of air quality along their route on a customisable graph in function of trip duration, distance, or absolute time. The dashboard also provides estimates of user exposure to air pollutants and allows interactive estimation of inhaled pollutant doses during trips by inputting gender, age, and activity. Furthermore, users can compare various trip graphs to identify the healthiest option among alternative trips in the neighbourhood, by identifying the best alternative routes, locate sources of contamination, investigate temporal effects, and compare similar sites across different countries or cities.

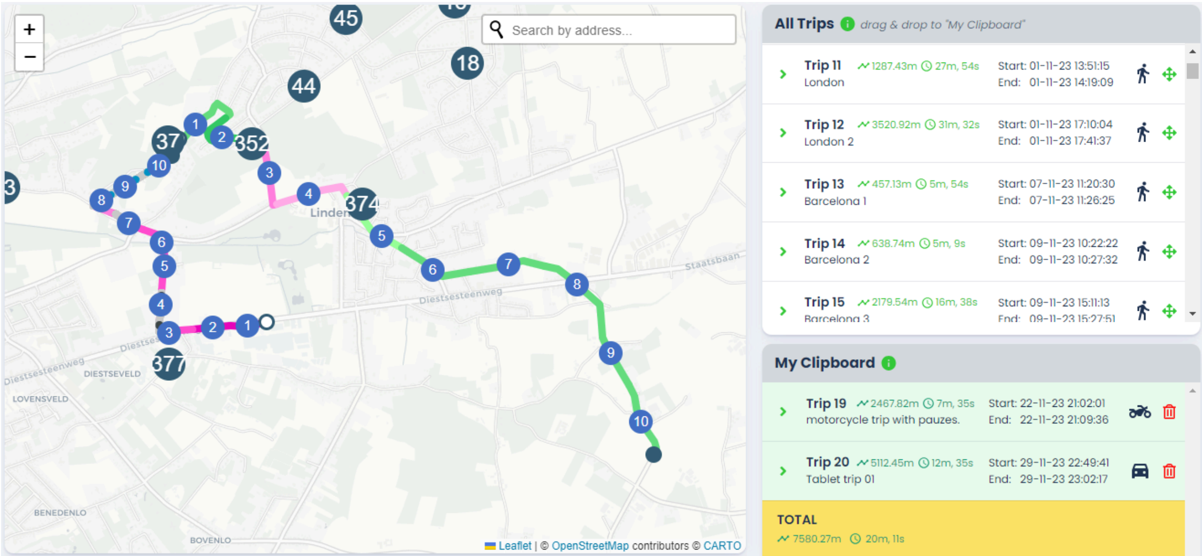

Figure 3 . Dynamic Exposure Visualization Dashboard (DEV-D)

2.3.3 Carbon Footprint Simulation Dashboard

The purpose of the Carbon Footprint Simulation Dashboard (CO2) is to guide users to improve their behaviours through more environmentally friendly choices, regarding their carbon footprint. To fulfil the pilot's requirements, the Carbon Footprint Simulation Dashboard includes two tools: the Carbon Footprint Calculator and the Scenario Simulation Dashboard. Carbon Footprint Calculator is designed to help citizens realise how their carbon footprint is affected through their daily actions and to give recommendations on ways to reduce their footprint. Using the CO2 Calculator, a person can calculate their carbon footprint by answering a set of questions related to their daily activities, such as transportation, energy use, and recycling. They can examine which of these aspects contribute the most to their carbon footprint. They can compare their emissions with the average in their country, Europe, or other dashboard users. At the end, people get recommendations on how to reduce their footprint by introducing changes to their daily activities and habits.

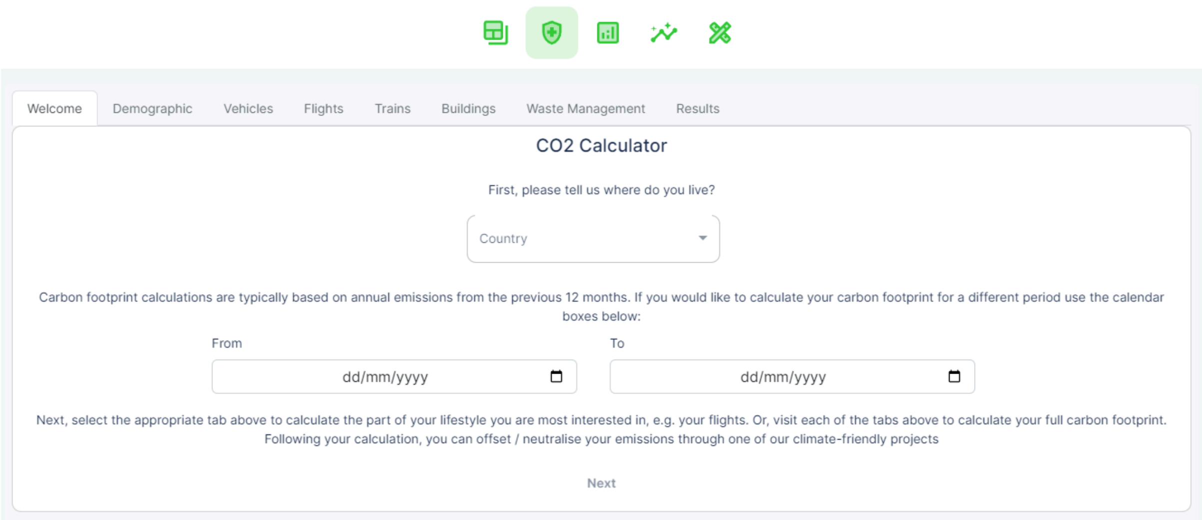

Figure 4 . Carbon Footprint Calculator

The second tool, the Scenario Simulation Dashboard, will help citizens to take part in policymaking. After the calculation of their carbon footprint, citizens can move from an individual to a collective level. With the Scenario Simulator, users have the ability to create scenarios based on their understanding of how to achieve the European Commission's target of a 55% net reduction in greenhouse gas emissions by 2030. Actions to achieve this target are based on what an average citizen would be willing to change in their life and what they would be willing to accept from the government (local, national). Each action has several sub-actions that can be modified by playing with a slider. On the left-hand side you can see a few example scenarios so you can better understand how the Scenario Simulation works. For example, the pessimistic scenario shows how nothing will improve if no action is taken, while the realistic scenario shows how citizens can affect the reduction of greenhouse gas emissions with little effort.

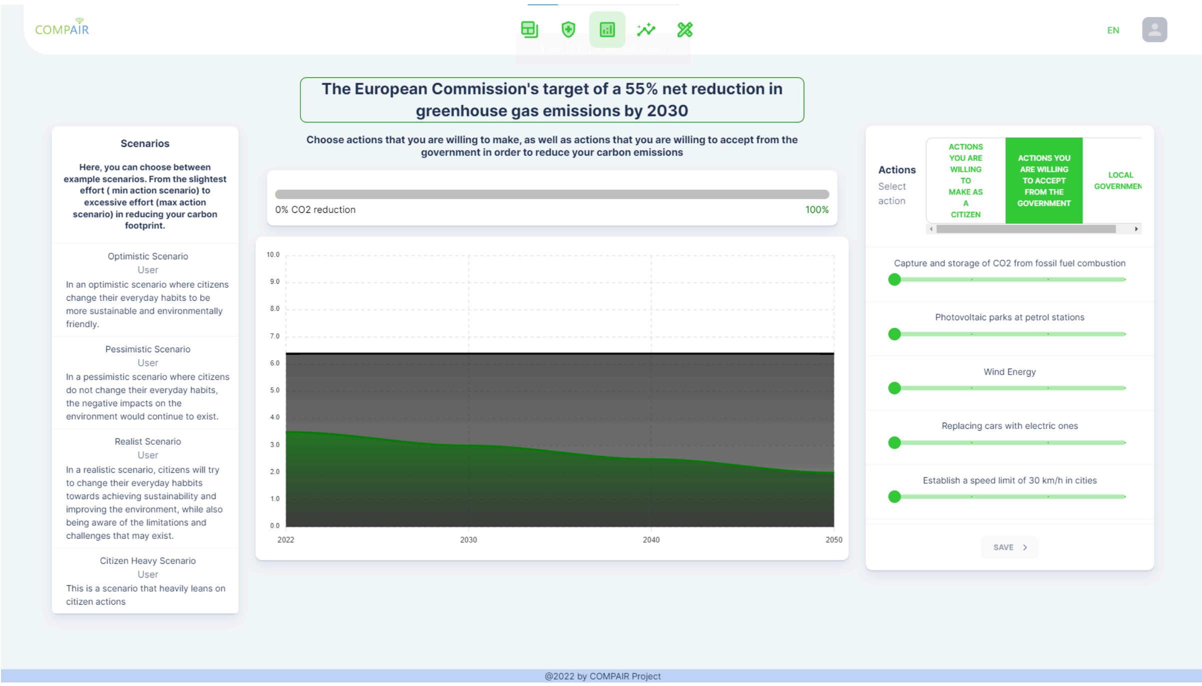

Figure 5 . Scenario Simulation Dashboard

2.3.4 Dynamic Exposure Visualisation Application (DEVA)

The Dynamic Exposure Visualisation Application (DEVA) is to enable citizens to explore the environmental conditions in their surroundings via their smartphone or tablet using Augmented Reality (AR). So they see a visual overlay of environmental information such as air quality.The app shows, on mobile devices optimised for AR, air pollution as floating particles such as spheres, stars, pins or cubes. Pollution intensity can be displayed as clouds in gradients of different colours.

DEVA ingests data from citizen science sensors, official monitoring stations and air quality model data. The app provides detailed sensor information for a variety of pollutants like CO2 (Carbon Dioxide), NO2 (Nitrogen Dioxide), BC (Black Carbon) and PM1, PM2.5 and PM10 (Particulate Matter of size 1, 2.5 and 10 micrometres), as well as humidity and temperature.

Furthermore, the app can record trips and save current GPS positions, thus making it possible to monitor air quality along the route. The recorded data serves as input to the Dynamic Exposure Visualization Dashboard (DEV-D).

DEVA is currently available as an open testing version on Google Play Store. An iOS version will be released soon.

Figure 6 . Dynamic Exposure Visualisation Application (DEVA)

2.4 MoRRI Indicators analysis and assessment

Responsible Research and Innovation (RRI) involves engaging society in the early stages of research and innovation processes to ensure that the outcomes align with societal values. It serves as a broad framework that integrates various dimensions of the relationship between research, innovation, and society, including public engagement, open access, gender equality, science education, ethics, and governance. RRI is also a key focus area within Horizon 2020, the EU's Research and Innovation Programme for 2014-2020 (European Commission, 2018).
One of the indicators COMPAIR has chosen to help measure the impact of its work and more specifically the evaluation evidence concerning the societal, democratic and economic costs and benefits of citizen science, is the MoRRI indicator. Importantly, COMPAIR will help sustain impact from technology-enabled citizen science by contributing to the the MoRRI indicators as follows:

Table 1: *MoRRi Indicators*

MoRRi Indicator	COMPAIR Contribution
SLSE 4.2 - Citizen Science activities in RPOs	**COMPAIR** published a number of scientific papers, with at least one towards policy makers with the lessons learned, and one regarding how Citizen Science projects can influence the scientific agenda. Citizen scientists and pilot members were co-authors.
PE1 - Models of public involvement in Science & Technology decision making	**COMPAIR** evaluated the degree to which CS Labs, design thinking, and technology involve citizens, especially LSE groups, in active citizen science actions as well as in policy decisions.
PE2 - Policy-oriented engagement with science	**COMPAIR** co-created policy-related dashboards and use an existing City Digital Twin solution (cf. DUET project) in close cooperation with scientists. The dashboards itself were open to the public so that also amateur scientists and involved citizens can be involved.
PE3 - Citizen preferences for active participation in S&T decision making	**COMPAIR** invited citizens to be actively involved. The involvement was monitored, and strategies will be tested to keep citizens on board. Especially new insights became available about the involvement and degree of long-term participation of LSE and disadvantaged groups.
PE10 - National Infrastructure for involvement of citizens and societal actors in R&I	**COMPAIR** increased the number of citizens, societal actors and policy makers involved in research and innovation. Our methods for stakeholder mapping, engagement and retention were shared as best practice locally and nationally.

2.4.1. SLSE 4.2 - Citizen Science activities in RPOs

The COMPAIR project addressed the first MoRRI Indicator, SLSE 4.2 - Citizen Science activities in RPOs, through the publication of seven papers. The list with the scientific papers is presented in the table below:

Table 2: *Publications of COMPAIR*

Publications of COMPAIR	Type and name of Journal	# Reads/ Views
Designing Citizen Science tools towards increased awareness and participatory policy making for air quality: The Case of COMPAIR	Conference proceedings 18th International Conference on Environmental Science and Technology	74 (14.09.24)

Analysing the indicators and the associated recommendations of household emission calculators	Conference proceedings 18th International Conference on Environmental Science and Technology	74 (14.09.24)
Assessing the Correlation between Citizen Science and Carbon Footprint: Introduction of COMPAIR's CO2 Calculator	Scientific Journal Energies	1426 (14.09.24)
Forging the Future of Responsive Cities Through Local Digital Twins	Quarterly magazine ERCIM News 127/ Special theme: Smart and Circular Cities	3974 (14.09.24)
Tackling air pollution with citizen scienceResearch and Innovation	Publications Office of the EU Green Deal projects success stories	74 (14.09.24)
Improving Urban Air Quality and Climate-resilience in Cities with Inclusive, Policy-relevant Citizen Science	Quarterly magazine ERCIM News 135/ Special theme: Climate Resilient Society	1276 (14.09.24)
Dynamic Exposure Visualisation of Air Quality Data with Augmented Reality	Conference proceedings 18th International Conference on Environmental Science and Technology	74 (14.09.24)

These publications from the COMPAIR project examine various aspects of citizen science, environmental monitoring and policy engagement. They emphasise the need for greater acceptance of citizen science as a reliable source of data in policymaking and explore the project's efforts to engage diverse, often underrepresented communities in environmental monitoring, particularly in urban settings. Publications highlight the development and use of advanced digital tools such as the Policy Monitoring Dashboard, Carbon Footprint Simulation Dashboard and DEVA that help citizens and policymakers visualise and assess the impact of lifestyle choices and policy interventions in air and carbon quality. emissions. In addition, the project promotes sustainable transport and waste management practices by demonstrating the tangible impact of citizen-based data on local policy decisions. Through innovative approaches such as Augmented Reality and the Scenario Simulation Dashboard, COMPAIR aims to promote greater environmental awareness and behavioural change among citizens, providing policy makers with valuable citizen input to take into account in the decision-making process, which will contribute to the creation of climate resilient communities.

With these publications, COMPAIR has succeeded in reporting on scientific engagement, showcasing its dashboards, digital twins, innovative approaches to air pollution through citizen science, and strategies to raise awareness and promote participatory air quality policymaking through citizen science tool development. It is evident from the results of the above indicators (Table 2) that COMPAIR achieved its KPI’s in greater engagement towards the scientific community and citizen scientists. It is worth also to mention that our scientific publications present a mean citation rate of 2 taking into consideration they were published in 2023 - 2024.

The first publication of the project was in the October 2021 issue of ERCIM News 135, on the Special theme: Smart and Circular Cities, titled "**Forging the Future of Responsive Cities Through Local Digital Twins**". It was a primary announcement of COMPAIR's intention to follow the example of the DUET digital twin initiative, but it was not only that. It also explained that COMPAIR provides citizens with the tools and resources to identify and address local air quality issues. It also refers to how introducing the concept of "citizen science" is intended to facilitate the integration of social and emotional intelligence into the decision-making process. Assisting policy makers in building capacity to engage and involve citizens from all sections of society in decision-making processes, particularly those who are hard to reach and belong to lower socio-economic groups, COMPAIR can help eliminate biases from the conventional methods of consultation. The COMPAIR initiative will facilitate access to digital twin interfaces, enabling participants to view and understand urban data. In addition, it will equip them with the ability to identify relevant issues, collect data through sensor deployment, and upload anonymized personal information, including emotional responses to specific locations and environmental conditions. Incorporating more sophisticated spatiotemporal data into local digital twins, COMPAIR enables a more accurate representation of the urban experience, facilitating data-driven decision-making processes and enhancing the potential for co-creation of social benefits. In conclusion, the COMPAIR initiative strives to promote the development of intelligent urban environments that respond to the needs of their citizens (Mark McAleer et al., 2021).

Another significant publication is "**Assessing the Correlation between Citizen Science and Carbon Footprint: Introduction of COMPAIR's CO2 Calculator**" and reports on the development of the Carbon Footprint Simulation Dashboard and the use of citizen science (CS) data to help citizens understand and compare how future carbon emissions could change based on adjustments to their daily lives. This study presents the Carbon Footprint Simulation Dashboard, its features and how it aims to assess citizens' carbon footprints and to offer a unique advantage by gathering their views on the actions they are willing to undertake to achieve policy goals. The inclusion of citizen science in the COMPAIR project enriches public and private data on air quality and ensures that citizen science is a credible approach to addressing environmental issues (Orfanou et al.,2023).

This paper highlights the dual purpose of the Dashboard: to raise public awareness of environmental issues and to encourage public participation in policy making. On the one hand, the Dashboard enables citizens to understand the sustainability of different modes of transport (such as air, rail and car) and their household habits. It shows that heating buildings and the energy consumption associated with it accounts for almost half of CO2 emissions, while transport also plays a significant role in carbon production. The study shows an interesting relationship between the carbon footprint of citizens and their waste management behaviour, in particular the impact of recycling, composting and energy recovery, which can account for up to 7% of CO2 emissions. On the other hand, the development of a scenario simulation dashboard allows citizens to estimate potential reductions in their carbon footprint by making informed choices about their behaviour and the government policies they support. This tool encourages citizen participation in policy making and motivates them to adopt environmentally friendly practices (Orfanou et al.,2023). An early version of this paper was presented in the ECSA 2022 Conference Citizen science for planetary health Oct 2022 as an oral session with the title: The role of sustainable waste management in the carbon footprint of pilot cities: Presenting the CO2 calculator of COMPAIR.

Related to this previous publication is the paper presented at the 18th International Conference on Environmental Science and Technology, Athens, Greece, 2023, "**Analysing the indicators and the associated recommendations of household emission calculators**". This study shows the current state of household carbon footprint calculators and the data they require from their users in order for them to calculate their carbon footprint and any recommendation they may provide based on the results. This is achieved by analysing a list of carbon footprint calculators that are freely available online and, specifically, the domains and indicators each calculator uses, along with the associated resulting recommendations. It is an ideal introduction to the presentation of the COMPAIR's tool, Carbon Footprint Simulation Dashboard, that was mentioned earlier, as it highlights the research gaps it comes to fill (Alexopoulos et al.,2023).

An important publication is regarding the DEVA application called "**Dynamic Exposure Visualisation of Air Quality Data with Augmented Reality**", which won the best poster award at GISTAM 2024. This Augmented Reality (AR) application provides, for the first time, real-time visualisation of air quality and traffic data based on publicly available DIY environmental sensor data. The overall framework of DEVA follows a flexible and dynamic software concept that can easily be extended with additional functionality according to user needs and the availability of new sensor data. For example, the inclusion of gamification elements could be used in future versions to increase the attractiveness and enjoyment of the application, especially for younger audiences. The main contribution of this paper is the proposal of three different types of visualisations for 3D data in the 3D AR space. Thanks to the H2020 project COMPAIR, the development of the different prototypes was continuously accompanied by the project partners. Thus, the UI design and the required functionalities are the result of in-depth testing and evaluation thanks to the CS-based nature of the project. The app will be released to the public on app stores by mid-2024 (Renault et al., 2024).

"**Designing Citizen Science Tools for Increased Awareness and Participatory Policy Making for Air Quality: The case of COMPAIR**" is another publication from the COMPAIR project, presented at the 18th International Conference on Environmental Science and Technology, Athens, Greece, 2023. In this paper, COMPAIR addresses the lack of digital solutions that allow users to explore citizen science data in a more intuitive and immersive way, by presenting the creation of new digital tools - web-based and mobile - that use advanced analytics, that help users understand how individual lifestyle choices and government policies affect different indicators, simulation and AR to make citizen science data more insightful and more effective for city stakeholders. The project uses a cloud-based remote calibration approach to improve the quality of the underlying data, ensuring that data visualisations are not only attractive, but also accurate. The involvement of Quadruple Helix stakeholders at various stages of the project, from experimental design to site selection, data collection and policy recommendations, is expected to improve the validity of the final results and their eventual acceptance by the intended audience. Overall, these efforts give a more reliable picture of the local reality regarding air quality and the related sectors on which it depends, e.g. mobility, energy consumption, waste management. It is a picture that provides the basis for dialogue and participatory policy-making, a key tool for moving to a more sustainable future that is green, digital and fair (Kogut et al., 2023a).

In the October 2023 issue of ERCIM News 135, on the Special theme: Climate Resilient Society, the COMPAIR consortium published the article "**Improving Urban Air Quality and Climate-resilience in Cities with Inclusive, Policy-relevant Citizen Science**". With this article, COMPAIR wanted to communicate how through its community-based approach and innovative tools, it is improving urban air quality while redefining citizen engagement in environmental science. By aiming for both inclusive engagement and impactful policy change, COMPAIR demonstrates that a balanced strategy produces more sustainable outcomes than one that emphasises engagement or policy influence alone. This dual approach is central to COMPAIR, which uses citizen science to improve urban air quality and build climate resilient communities in Athens (GR), Berlin (DE), Flanders (BE), Plovdiv and Sofia (BG). The project actively involves groups that are often vulnerable to air pollution and typically underrepresented in citizen science, such as young people, the elderly and minority communities. Reaching these groups can be challenging due to factors such as age, mistrust, language barriers and low digital literacy. COMPAIR's strategy is to work with organisations that already have established links with these communities, including charities, community centres and schools (Kogut et al., 2023b).

In addition, within the project of COMPAIR, there has been published a success story on the Green Deal projects success stories, titled "**Tackling air pollution with citizen science**". In this story it has been described how COMPAIR's achievements across various locations underscore the project's adaptability and widespread impact. It emphasises that the essence of COMPAIR lies in its community-centred methodology, where data collected by citizens is calibrated and disseminated through open dashboards and mobile apps, empowering volunteers and policymakers to make informed decisions. By bridging the gap between scientific knowledge and community action, COMPAIR is at the forefront of developing a greener, more sustainable future. Some of the highlights of the project are that it has redefined citizen participation in scientific research, engaging diverse communities such as the elderly in Athens and Roma groups in Sofia to tackle air pollution. The project made significant progress by incorporating environmental science into education in Flanders and

Plovdiv, encouraging environmentally aware students through hands-on activities and data collection. The impact of COMPAIR also extends to local policy making, providing hyper-local data that has influenced urban planning and traffic management, including the assessment of low-traffic neighbourhoods in Berlin and the implementation of school streets in Herzele, Flanders. It has also promoted sustainable transport solutions, such as the school bus initiative in Sofia, which reduces emissions around schools. The creative engagement of participants, particularly in Sofia where students used art and poetry to express their environmental knowledge, underlines the project's broad approach to supporting communities and environmental sustainability (European Commission, 2024).

2.4.2 PE1 - Models of public involvement in Science & Technology decision making

Based on the lessons learned from the D5.6 Public Round Report, the COMPAIR project highlighted the importance of public involvement in science and technology decision-making, which is directly linked to the MoRRI PE1 indicator. Through workshops, sensor distribution and tool campaigns (DEV-D, DEVA, PMD, Carbon Footprint Simulation Dashboard), it became clear that the involvement of citizens, including the lower socio-economic (LSE) teams, is essential for successful citizen science initiatives. For example, the Athens pilot successfully engaged elderly citizens through existing networks such as friendship clubs, highlighting the importance of accessible and inclusive participation models. Working with NGOs, schools and municipal authorities, the pilot not only raised awareness of air pollution and its health effects, but also empowered participants to understand the link between their behaviour and environmental quality. The use of multiple communication channels, including the Synathina platform, facilitated broad engagement, while the data collected provided valuable information for future urban planning and policy development. This approach demonstrates how inclusive citizen science can directly contribute to informed decision-making and promote community-driven solutions.

Similarly, the Berlin pilot demonstrated the value of community involvement in air quality monitoring, using both mobile and static measurements to engage citizens in understanding air pollution. The pilot's workshops and hands-on training sessions empowered participants with the skills to monitor their environment, creating a knowledgeable and proactive community better equipped to influence policy debates. The data collected by citizen scientists filled the gaps in Berlin's official monitoring network, but also sparked a focused dialogue with local initiatives and the city government, highlighting the potential of citizen science to shape urban policy.

In Flanders, the focus of the pilot on school road initiatives in Herzele and Ghent exemplifies the MoRRI indicator 'Models of public participation in science and technology decision-making' by involving local communities, particularly students, in environmental monitoring and policy evaluation. Educational activities in primary and secondary schools have raised awareness and encouraged behavioural change. By actively participating in traffic and air quality monitoring, students and local residents provided valuable data that informed discussions on mobility and pollution control. Partnerships with local councils and environmental groups extended the impact of the project, providing a successful model for citizen participation in local policy making. The community-driven data collection and the positive response from participants highlight the potential of such initiatives to guide current and future policy decisions towards a more sustainable urban environment.

The Sofia and Plovdiv pilots also demonstrated the importance of citizen participation in environmental decision-making, despite technical challenges that limited the use of some sensors. In Sofia, the focus was on the CO2 Calculator and the Carbon Footprint Simulation Dashboard, tools that enabled citizens to actively participate in assessing their environmental impact and provided critical feedback for further tool development. Engaging school-age and kindergarten children through hands-on experiments and new school bus routes demonstrated how early educational interventions can influence long-term behaviour change and community sustainability practices. Meanwhile, in Plovdiv, pilot efforts to link traffic patterns to air pollution through school monitoring highlighted the role of participatory approaches in urban planning. By incorporating citizens' feedback and suggestions into urban plans, these pilots demonstrated the value of community participation.

2.4.3 PE2 - Policy-oriented engagement with science

COMPAIR's dashboards were designed to address the MoRRI Indicator related to policy-oriented engagement with science. The intuitive built-in analytics enable users to evaluate the effects of personal lifestyle choices and government policies on various indicators, such as EU Green Deal targets, the MoRRI Indicators and Sustainable Development Goals (SDGs) goals, providing a clearer understanding of potential outcomes before actions are taken. The dashboards itself are open to the public so that also amateur scientists and involved citizens can be involved.

These dashboards, such as the Policy Monitoring Dashboard (PMD), were co-created to support the monitoring of target locations and surrounding areas, helping assess whether a policy intervention effectively solves a problem or merely shifts it elsewhere (the displacement effect). By aggregating extensive citizen science data within specific settings, the dashboard provides valuable insights into the impact of various policy implementations on traffic and air quality.

Also the second tool of the Carbon Footprint Simulation Dashboard, the Scenario Simulation Dashboard, allows users to contribute their opinions by creating scenarios aligned with specific environmental goals. For example, a goal might be the European Commission's target of a 55% net reduction in greenhouse gas emissions by 2030, displayed prominently at the top of the page. This tool enables users to visualise how different actions could impact their carbon footprint while providing policymakers with valuable citizen input to consider in their decision-making processes.

Another goal of COMPAIR to address this MoRRI indicator, was to use an existing City Digital Twin solution from the DUET project in close collaboration with scientists. This was successfully done as reported in the D3.6 Digital Twin CS Integration deliverable. Different types of citizen science sensor data were collected in the COMPAIR project, detailing the standardisation and calibration procedures that enhance the integration of CS data into a Digital Twin. It also covers the integration approach used in the DUET project, which integrates similar sensor data into the Flanders and Athens Digital Twins. The presented results and examples from the developed Digital Twins illustrate how CS data can be effectively combined with other data sources and integrated into a Digital Twin, supporting evidence-based decision making.

2.4.4 PE3 - Citizen preferences for active participation in S&T decision making

As part of Task 5.5, 'Co-innovation to build capacity and create new services', various co-innovation strategies and activities were implemented to engage citizens in policy-making in all pilot sites using COMPAIR sensors and digital tools. The following is an overview of the different formats used by the pilot programs to foster co-innovation and promote citizen science and participation in decision-making.

The main activities focused on engaging citizens through the tools provided by COMPAIR, allowing participants to explore social issues, analyse and interpret data, gain knowledge or solve specific problems. Co-creation workshops involving stakeholders, experts and citizen scientists were a key component of the innovation process. These workshops focused on collaboratively defining the scope of experiments, generating or analysing datasets, and deriving valuable results and insights. They proved effective during both the Public and Open round testing phases and were used by all COMPAIR pilots.

In Flanders, Berlin and Athens, static and mobile measurement campaigns were carried out to collect data for analysis. These campaigns were necessary to integrate real-time quantitative data into the digital tools developed by COMPAIR, such as the Policy Dashboard (PMD), DEVA and DEV-D applications. Data Cafés and Hackathons, particularly in Flanders and Athens, have been instrumental in promoting co-innovation and co-creation. These events focused on data analysis and interpretation, creating interactive engagement opportunities and innovation spaces where participants could discuss data, deepen understanding and develop smart solutions.

In Sofia and Plovdiv, ideathons—a collective brainstorming event aimed at generating innovative ideas to address specific challenges—were implemented. These time-limited sessions emphasised ideation over implementation, harnessing the collective creativity of participants.

Finally, awareness campaigns in Sofia, Plovdiv and Athens marked the final phase of the co-creation process. These campaigns were used to introduce COMPAIR digital tools to the public and local authorities, broadening citizen participation in science activities.

As it is mentioned in the deliverable D5.6 Public round report, through these workshops, local recruitment campaigns, school lessons and other engagement events COMPAIR managed to directly reach about 3300 citizens with at least an additional 25000 through indirect forms of engagement. Based on available statistics and proxies it is estimated that 23% (>700) participants are from lower socio-economic (LSEs) groups.

3.4.5 PE10 - National Infrastructure for involvement in R&I

As described in Deliverable D5.7 Co-innovation Report 2, a wide range of co-innovation activities were carried out by the COMPAIR pilots in Athens, Berlin, Flanders, Plovdiv and Sofia during the public test phase.

First, a collaboration and co-innovation approach was instrumental in the development of key COMPAIR platforms such as the Policy Monitoring Dashboard (PMD), the Dynamic Exposure Visualization Application (DEVA) and the Carbon Footprint Simulation Dashboard. The citizen science methodology was also instrumental in refining and improving the features of the sensors provided by both the consortium and external partners. During the public testing phase, all devices provided by COMPAIR were tested and feedback from citizen scientists led to significant improvements in performance and accuracy of their measurements. This co-innovation process benefited partners such as SODAQ, Telraam and IMEC, while for the bcMeter devices, it resulted in a new prototype with an updated 3D housing. This collaboration with citizens not only improved the products but also enhanced integration with COMPAIR's digital dashboards, leading to greater satisfaction and pride among participants.

The COMPAIR digital platforms themselves served as tools for co-creation and collaboration between citizens and politicians. For example, the Carbon Footprint Simulation Dashboard, PMD, and mobile apps provided policymakers and city officials with valuable data, helping them make more informed policy decisions.

In addition, collaborative innovation was implemented at the municipal level, leading to the development of a pilot school bus service in Sofia, a pilot street school in Flanders and the creation of the first map of wood burning incidents in Flanders. By combining different perspectives, expertise and resources, the pilots created innovative solutions and recommendations for local authorities. In addition, these citizen science experiments and co-innovation activities trained and supported officials in developing their strategies and data collection methods for policy making.

In conclusion, the assessment of the MoRRI indicators throughout the project confirms that COMPAIR’s strategy and tools align perfectly with them. COMPAIR's use of these indicators, particularly those that evaluate the societal, democratic, and economic costs and benefits of citizen science, demonstrates its commitment to measuring the impact of its work effectively and contributes valuable evidence to the broader field of citizen science.

3. Performance of CS tactics per COMPAIR tool

In this chapter, the analysis will be carried out regarding the use of the tools in the project, in the light of MoRRI indicators. The table below lists which MoRRI indicators are covered by each tool.

Table 3: *MoRRI indicators covered by each tool.*

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
Policy Monitoring Dashboard (PMD)	PE1 - Models of public involvement in Science & Technology decision making	PMD project for air quality in Neos Kosmos	23 citizens participated
		PMD project for air quality in Kypseli	32 citizens participated (1 dropped out)
		PMD project for NO2 in Athens	150 citizens participated in both areas
		PMD project for air quality in Plovdiv - Dimitar Talev school	around 800 students participated
		PMD project for air quality in Plovdiv - Vasil Levski school	around 35 volunteers participated
		PMD project for air quality in Plovdiv - Knyaz Alexander I school	around 1200 students participated
		PMD project for air quality in Sofia - 18th Secondary School "William Gladstone"	24 students direct participants in a workshop and measurements; the school is 2300+ students
		PMD project for air quality in Sofia - 32-nd Secondary School "St. Kliment Ohridski"	48 students direct participants in workshops and measurements; the school is 1900+ students

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Raising awareness campaign about the school bus service and surveys among parents	
		PMD project for air quality and traffic measurements in Berlin-Mitte and Berlin-Neukölln (static campaign), awareness raising as well as training, testing and the usage of the tool (PMD)	in total 19 participants in static campaign of both areas; only 12 could use the PMD, for the other participants the tool didn't work due to technical difficulties that couldn´t be solved; 9 participants dropped out of the static campaign
	PE3 - Citizen preferences for active participation in S&T decision making	Static and mobile measurement campaigns to collect data for analysis in Flanders, Berlin, Athens.	Athens: 10 workshops including 55 SODAQ sensors for static measurements and 9 sensors.community that were retrieved Berlin: 3 workshops with the participants from both campaigns; static campaign: 15 SODAQ air devices, 5 bcmeter air devices, 8 Telraam traffic devices; mobile campaign: 45 SODAQ devices
		Static measurement campaigns to collect data for analysis in Plovdiv	60 direct participants in measuring campaigns for AQ and traffic, 4 training (2 trainings for DIY PM10 sensors and 2 trainings for Telraam v1 sensors) of the volunteers on sensor installation, maintenance and data visualisation. Organising 2 sensors exchange

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Static measurement campaigns to collect data for analysis in Sofia	campaigns -1 for DIY PM10 and 1 for traffic sensors 200+ direct participants in measuring campaigns
		Campaigns regarding PMD to integrate real-time quantitative data into the digital tools developed by COMPAIR	
	PE2 - Policy-oriented engagement with science	PMD provides valuable insights into the impact of various policy implementations on traffic and air quality.	Achieved though the pilot implementation in Flanders.
	PE10 - National Infrastructure for involvement in R&I	Collaboration and co-innovation approach was instrumental in the development of PMD.	More than 2300 citizens participated in PMD projects in the pilot cities.
		Citizen science methodology was also instrumental in refining and improving the features of PMD.	With the participation of more than 2300 citizens in PMD projects in the pilot cities.

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Provide policymakers with valuable data, regarding citizens actions that impact their carbon footprint, helping them make more informed policy decisions.	Achieved
Dynamic Exposure Visualization Dashboard (DEV-D)	PE1 - Models of public involvement in Science & Technology decision making	Raising awareness of air quality with students of the college of Geel & the University of Leuven.	
		Workshop with schoolchildren by the VMM & DV in Herzele	
		Mobile measurement campaign in Berlin: Raising awareness of air quality and traffic with commuting cyclists from Berlin; as well as trainings and testings with SODAQ air devices with commuting cyclists	45 participants in total of the mobile campaign; only 14 were able to use the DEV-D tool; not more due to technical problems; 11 cyclists dropped out of the campaign

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Trainings of students and volunteers in Plovdiv - air quality, sensors installation and maintenance	more than 150 participants
		Rising awareness campaign for students and other stakeholders in Plovdiv	More than 230 participants
		Trainings and testings for mobile measurements with SODAQ Air devises in Sofia and raising awareness campaign for students and other stakeholders in Sofia, such as cyclists - volunteers in testings	200+ direct participants in workshops and measuring campaigns
	PE3 - Citizen preferences for active participation in S&T decision making	Campaigns regarding DEV-D to integrate real-time quantitative data into the digital tools developed by COMPAIR.	14 people were able to use the DEV-D tool in Berlin
Carbon Footprint Simulation Dashboard	PE1 - Models of public involvement in Science & Technology decision making	Workshops, campaigns and an ideathon dedicated to the CO2 calculator to citizens and Sofia municipality	75+ participants 400+ visits from Sofia raising awareness campaign with 40 locations of advertising sports in Sofia 20+ posts in social media

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		CO2 calculator campaign to municipal employees of the City of Athens	more than 5000 contacts
		Online campaigns through diverse communication and networking channels in Athens	Social media posts, 3 major campaigns in online newspapers are ongoing (September 2024) in Kathimerini.gr, CNN.gr and news247.gr, online promotion
		CO2 calculator as a part of rising awareness campaign in Plovdiv	more than 100 participants
	SLSE 4.2 - Citizen Science activities in RPOs	Publication on Energies Journal regarding the introduction of the Carbon Footprint Simulation Dashboard	1420 reads
	PE2 - Policy-oriented engagement with science	Carbon Footprint Simulation Dashboard provides policymakers with valuable citizen input to consider in their decision-making processes.	Achieved with 25 unique users visiting the admin/policy maker area of the dashboard.
	PE10 - National Infrastructure for involvement in R&I	Collaboration and co-innovation approach was instrumental in the development of Carbon Footprint Simulation Dashboard	Achieved through seven workshops between Greece (Athens and Samos), and Bulgaria (Sofia and Plovdiv), with more than 5400 contacts.

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Citizen science methodology was also instrumental in refining and improving the features of Carbon Footprint Simulation Dashboard	
		Provide policymakers with valuable data, helping them make more informed policy decisions.	
Dynamic Exposure Visualisation Application (DEVA)	PE1 - Models of public involvement in Science & Technology decision making	Raising awareness of air quality with students of the college of Geel & the University of Leuven.	
		Workshop with schoolchildren by the VMM & DV in Herzele	

COMPAIR tools	MoRRI indicator	Applied CS tactics	CS tactics performance
		Mobile measurement campaign in Berlin: Awareness raising as well as training and testing with commuting cyclists by using SODAQ devices and the DEVA	due to the reason that the APP only worked for Android user and the first version faced some technical challenges only 20 of the 45 participants of the mobile campaign used the APP; the second version worked smoothly and 3 more participants tested and used the APP
	PE3 - Citizen preferences for active participation in S&T decision making	Campaigns regarding DEVA to integrate real-time quantitative data into the digital tools developed by COMPAIR	
	PE10 - National Infrastructure for involvement in R&I	Collaboration and co-innovation approach was instrumental in the development of the dashboards. Citizen science methodology was also instrumental in refining and improving the features of the dashboards.	Achieved

Table 3 demonstrates that the selected MoRRI indicators were effectively addressed across all four tools used in the pilot cases, highlighting COMPAIR’s success in meeting its KPIs, in engagement with the scientific community and in deeper involvement from citizen scientists. Moreover, the pilot cases led to the development of several citizen science tactics, that are presented in the next chapter, aimed at overcoming challenges related to participation. These tactics emerged though pilots lessons learned and as direct responses to the unique barriers faced by different communities within the pilot cases.

4. Recommendations for Citizen Science Tactics application

By implementing citizen science tactics identified through lessons learned from the COMPAIR project pilots, future citizen science initiatives can significantly improve participation, data quality, behavioural change, and their overall impact on community engagement and policy-making. From the Public Round, the pilots have provided valuable lessons learned that have been incorporated into the Deliverable D5.6 Public Round report. For example, in Berlin, the challenges of the non-functioning bcMeter and growing frustration and drop-out rate among the static measurement participants highlighted the importance of smooth technology. The approach of working together with administrations from the very beginning to obtain usable data and generate findings that can be truly utilised, as in Flanders, is a central building block for both citizen science projects in general and for the field of air quality and mobility measures. Focusing on structural issues that block behavioural change (like improved cycling infrastructure) can unlock individual behaviour change in cases where citizens have little leverage over their behavioural options. These insights have led to the introduction of new citizen science tactics per pilot that are presented below.

These citizen science tactics align with the strategies outlined by Benye et al., 2023, which provide targeted recommendations for addressing common challenges in citizen science projects. Key strategies include dedicating time and resources to enhance both local and global networks and re-centering projects around community knowledge and participants' needs through open communication and co-creation at every stage—from design and implementation to dissemination and evaluation. The paper also emphasises the importance of enforcing codes of conduct, protocols, and data management practices that amplify community voices while avoiding colonial scientific approaches. It advocates for the use of adaptive, low-tech tools suitable for the local context and highlights the value of collaborating with local organisations and intermediaries who can act as project coordinators, decentralising management (Benye et al., 2023).

4.1 Citizen science tactics to address participation challenges

From the lessons learned during the Public Round (the final one, in which more citizens participated) of all the pilots, several citizen science tactics emerged to address challenges related to participation, including:

Reaching LSES and disadvantaged groups:

In Athens, the project successfully engaged elderly individuals, while in Flanders, outreach efforts targeted low socio-economic status (LSES) groups through school initiatives. In Plovdiv and Sofia, the focus was on connecting with students from LSES backgrounds and engaging Roma communities to address air pollution challenges.

According to the overall assessment presented in the D5.6 Public Round Report, COMPAIR successfully engaged participants from lower socioeconomic backgrounds, with an estimated 20% of total participants belonging to this group.

Maximising participation in citizen science projects can be achieved by targeting specific demographic groups, such as elderly people who want to stay engaged and learn new skills. Targeting diverse schools is another effective approach, as it allows the project to reach a wider and more inclusive audience, including students from low socio-economic status (SES) backgrounds who typically do not participate in civic initiatives. Schools offer a naturally diverse environment for engagement, making it easier to connect with different demographic groups. Working with school leaders can help to carefully and inclusively identify and engage low SES students without singling them out. Giving them tasks that play to their strengths increases their participation, boosts their self-esteem and promotes more equitable participation in the project.

Recognizing the role of local champions and giving them what they need: Another very interesting CS tactic that emerged from the Flanders pilot and could apply to the other pilots as well, is to recognize different types of "local champions" within the community. For example, they could be technical champions who excel in the technical side of things, functional champions who have already leadership roles (teachers), and internal champions within the organisation who are motivated to take action themselves. It is important to provide them with the resources they need, like refresher courses on air pollutants, equipment such as Arduino sensor kits, weekly scrum meetings, and full access to platforms for sharing their ideas and expertise. These different types of champions can drive the project forward by providing expertise, leadership, and motivation.

Fostering interactive engagement through the "Data Café".
In three pilot cities, Herzele (Flanders), Saint-Nicolas (Flanders), and Sofia (Bulgaria), a data cafe was conducted, where data were presented among parents, active citizens, and municipal officials. A data café is a gathering place where you can look together and explain the data that has been collected during the project by the sensors and the effects of real policy measures, shown in the project's tools (PMD).

Share best practices of other pilots: Share lessons learned and good practices implemented in different pilot areas with other local authorities and stakeholders. For example, the solution of "school streets" to reduce traffic around schools or the introduction of school buses could serve as a model for other regions to address air quality issues around their educational institutions.

Joint workshops for cross-learning: Organise workshops which involve all groups across the project so they learn from each other and see things in context. This could elevate the quality of learning and provide better-informed citizen scientists.

Improving student engagement and community impact by bringing citizen science into schools: In most of the pilots a series of workshops was organised for the students, regarding air quality, the main pollutants, ways to measure them with DIY sensors and how to assemble a DIY (sensor.community) device. From the interaction with the school community the following CS tactics emerged:

- **Integrate citizen science activities with parts of the school curriculum**: Incorporate citizen science tasks into portions of your classroom studies, such as Environmental Science, Chemistry and Math for engaging active learning experiences. By making sensors during technology classes, or working over the data in maths class, keeps students busy with projects while improving their learning.

- **Engage students for wider engagement:** Remember to work with students as the engine for wider engagement even among their home and in community, especially those interested more in science experiments. Harnessing this energy can expand volunteer recruitment and support sustainable practices outside the classroom (with parents or friends).

- **Utilise the Snowball Effect in Schools**: Engage students in citizen science projects, particularly around air quality, to create a ripple effect that extends awareness and action beyond the classroom. Students can influence their families and friends, expanding the project's reach. Media coverage of school projects can further inspire other schools and communities to participate.

- **Develop Links with Schools and Community Networks**: Schools are a productive intervention point for delivering information to varied socio-economic groups, and students can help spread the effect of projects beyond their families into society. Initiatives like school bus service to introduce a school bus routes on the outskirts of the Low Emission Zone and to create a community building exercise with schools and stakeholders affected by the air pollution - kids, parents, teachers, and to start raising awareness on every citizen's behavioural choices along with testing new municipal service of the school busses, provides an alternative to the widely established model of driving your children to school by car.

Organise ideathons for different purposes: Organise workshops in the form of ideathons to provide several discussion sessions with stakeholders dedicated to the different case studies. These ideathons should be dedicated to the project's tools in order to demonstrate their features live (such as the carbon footprint simulation dashboard). It is also recommended to organise a small-scale ideathon to agree on key messages and coordinate efforts to ensure that local plans are effectively aligned.

Encouraging behavioural change through the project's tools: The willingness of citizens to reduce their energy consumption and use alternative means of mobility (public transport, bicycling, walking) proves the success of awareness campaigns. Future tactics could include more targeted campaigns that encourage specific behavioural changes based on the data collected, leading to broader environmentally friendly behaviours.

Use the project results for future urban planning: Leverage the project findings to create long-term plans for urban mobility and air quality. These results can inform future policy decisions and help the long-term effects of the project continue to shape city planning through an environmental scope. Introduce ideas as the garden streets (which is the end goal in Saint-Nicolas in Herzele), as a possible mobility measure to slow down car traffic in residential neighbourhoods.

Incorporation of campaign results into policy: The community's enthusiasm about the CO2 calculator campaign suggests that citizen science data could lead to being incorporated into local policy. This will not only make data more relevant, but also enhances citizen power by including them in direct decision making.

Adaptive communication strategies: Modify the communication strategies according to how stakeholders respond and participate in different levels. Postpone any surveys until stakeholders have had more of a chance to interact with the service or tool (better response rates). Tailor communication channels and messages for unique groups to keep them informed.

Figure 7 . Citizen science tactics to address participation challenges

4.2 Citizen science tactics to address technological, data and epistemological challenges

In response to technological, data and epistemological challenges the following tactics emerged:

Ensuring technical reliability and support for citizen science projects: All pilots stressed the importance of technical reliability and support for citizen science projects in order to keep citizens engaged. More specifically:

- **Ongoing support and troubleshooting**: Ongoing support and clear troubleshooting instructions are essential to handle common issues such longer battery life, data transmission etc. That would possibly mean providing continuous charging plugs to tackle these challenges.
- **Adequate technical preparation:** Ensure thorough testing and technical support for all devices and platforms used in the project. Address potential technical challenges early to prevent participant frustration and abandonment due to equipment failures or usability issues.
- **Access to reliable data and continuous technical support**: Citizen science tools (such as sensors, dashboards) must always work properly because citizen scientists would get demotivated otherwise. Having a reliable & simple user interface in place will decrease any downfall that users might have faced.

Collecting citizen feedback and having iterative and direct implementation of participants' feedback:

The importance of citizen feedback in improving the tools was highlighted in Athens, Sofia, Herzele and Berlin. Gathering feedback from participants and using it to improve tools and methods should be a standard approach. This will ensure the accessibility and effectiveness of the tools for all citizens. Create an iterative feedback loop (for the CO2 calculator, DEV-D, bcMeter) where you start with a smaller, more manageable version of the test before rolling it out to all users. Use this feedback to iterate on the tool before a wider release. This will ensure that the tool is fit for purpose for both those who will be using it and those at a higher level who will be making policy, even before such tools are released to a wider audience. Develop a responsive development process for apps and dashboards, where feedback from participants is directly implemented to improve functionality during the project. This approach can improve the user experience and increase the effectiveness of the tools.

User friendly tools: The challenges experienced by elderly people of using more complex sensors illustrate the importance to design simplified tools and devices. Making it easier with user-friendly, and easy-to-assemble equipment can increase participation.

Usage of low-cost sensors: Fill in the gaps in the official networks using accessible DIY sensors. Although less accurate, these sensors could be used as a method of observing trends and indications that something is out of the norm, preparing authorities to deploy resources to collect more accurate data.

Upgrade sensor technology for automatic data analysis: Upgrade sensors with features such as a dedicated on/off switch to prevent indoor measurements from skewing data. Improved sensors can lead to more accurate and reliable data collection, making analysis easier and more meaningful.

Improving public data visualization tools: Improve public visualization platforms to better represent data collected from mobile phone sensors. For example, adding a linear time versus PM2.5 plot could help users understand pollution trends more clearly and allow them to provide more accurate annotations and insights into their data logs.

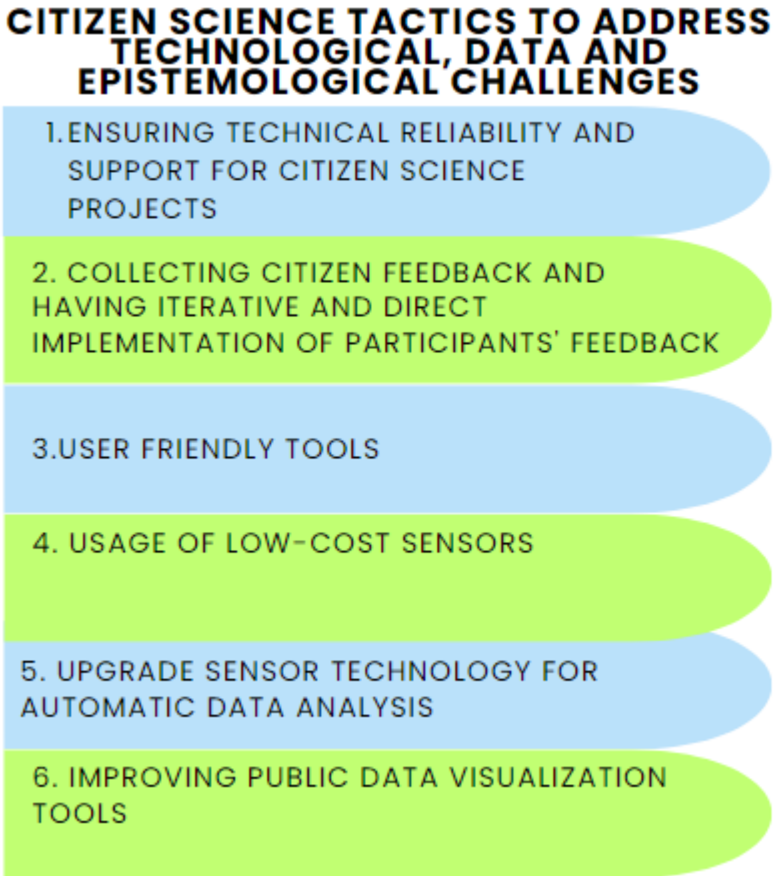

Figure 8. Citizen science tactics to address technological, data and epistemological challenges

4.3 Citizen science tactics to address ethical challenges

In response to ethical challenges of the project, the following tactics emerged:

Address Ethical Issues in Urban Planning: Be mindful of the ethical implications of urban projects that may disproportionately benefit middle or high SES communities while disadvantaged low SES neighbourhoods. Engage all affected communities in the planning and decision-making process to ensure equitable outcomes.

Privacy-first data collection: Address the principle of data minimization and privacy-by-design in citizen science projects, collecting only necessary data that is relevant to project goals. Ensure that data is stored securely and that participants are informed of their rights through clear consent forms and privacy policies.

Develop Tailored Consent Forms for Each Pilot Partner: Develop specific, tailored consent forms for each pilot partner that clearly communicate the scope, purpose and data management procedures of the project, using clear and plain language, taking into consideration the vulnerable communities that were involved. This approach ensures that participants are well informed about how their data will be used and stored, and promotes trust and ethical standards.

Figure 9. Citizen science tactics to address ethical challenges

5. Conclusion

COMPAIR enables communities to understand the direct impact of their actions on the environment by actively involving citizens in the collection and analysis of traffic, air quality and climate change data. Through its seven publications and participation in relevant scientific workshops or conferences, COMPAIR has successfully managed to report on scientific engagement by presenting its dashboards, digital twins, improved data interoperability, innovative approaches to tackle air pollution through citizen science, and strategies to raise awareness and promote participatory policy-making on air quality through the development of citizen science tools.

In addition, COMPAIR has carefully addressed the ethical challenges associated with its research activities, particularly due to its reliance on data collection through advanced technologies such as sensors and networks and the application of citizen science (CS) tactics to improve the quality of air in urban areas. The project was led by privacy by design principles to ensure data minimization and secure storage, with comprehensive consent forms and privacy policies to inform participants about the use of their data. In addition, all pilot campaigns were carefully designed to respect participants' rights and ensure compliance with GDPR regulations.

The pilot's case studies in Athens, Berlin, Flanders, Sofia and Plovdiv have demonstrated that citizen science tactics, identified through lessons learned, can significantly improve participation, data quality, behaviour change and overall impact on community engagement and policy making, providing valuable lessons for future citizen science initiatives.

These citizen science tactics highlight the importance of tailored approaches to encourage engagement, improve data quality and change behaviour. Key strategies include targeting specific populations, such as senior citizens, students or low SES groups, and simplifying tools to make them more user-friendly and accessible. Regular engagement with participants, regular communication about intermediate measurement results, ongoing technical support and feedback mechanisms were also highlighted as essential to keep participants motivated and overcome common challenges. Educational support, such as workshops and personalised feedback sessions, can significantly improve understanding of complex data and enable participants to contribute more effectively.

In addition, the pilots highlight the critical role of community engagement and adaptive communication in integrating citizen feedback into policy and decision-making processes. Tactics such as recognizing particularly enthusiastic participants as local champions and giving them what they need, using schools to reach diverse audiences, fostering collaboration through data cafés, and encouraging interactive feedback ensure that citizen science projects remain responsive to participants' needs. The findings underscore the importance of technical preparation, ethical considerations in project design, and the strategic use of citizen-collected data for future urban planning. Together, these lessons provide a blueprint for strengthening citizen science initiatives to ensure that they are inclusive, impactful and can lead to sustainable change at the community level.

The external validity of the identified citizen science tactics is supported by their alignment with the strategies proposed by Benye et al. (2023), which offer targeted recommendations for overcoming common challenges in citizen science projects. However, a limitation lies in the potential applicability of these tactics, as they may be most effective when implemented in pilots with similar profiles.

COMPAIR's impact is defined by its potential to inspire further experiments and initiatives that build on its pilot successes, sustaining the drive for positive environmental change. By continuing to engage and empower citizens through its tactics, citizens' awareness and sustainable behaviours fostered by COMPAIR will provide lasting benefits and contribute to society's ongoing efforts to address climate change.

References

Alexopoulos, C., Karelis, C., Keramidis, P., Orfanou, A., Lekkas, D. F., & Charalabidis, Y. (2023, August 30 - September 2). Analysing the indicators and the associated recommendations of household emission calculators. In Proceedings of the 18th International Conference on Environmental Science and Technology, Athens, Greece.

Benyei, P, Skarlatidou, A, Argyriou, D, Hall, R, Theilade, I, TurreiraGarcía, N, Latreche, D, Albert, A, Berger, D, Cartró-Sabaté, M, Chang, J, Chiaravalloti, R, Cortesi, A, Danielsen, F, Haklay, M, Jacobi, E, Nigussie, A, Reyes-García, V, Rodrigues, E, Sauini, T, Shadrin, V, Siqueira, A, Supriadi, Tillah, M, Tofighi-Niaki, A, Vronski, N and Woods, T. 2023. Challenges, Strategies, and Impacts of Doing Citizen Science with Marginalised and Indigenous Communities: Reflections from Project Coordinators. *Citizen Science: Theory and Practice*, 8(1): 21, pp. 1–15. DOI: https://doi. org/10.5334/cstp.514

European Commission: Directorate-General for Research and Innovation, (2024). *Green Deal projects success stories : tackling air pollution with citizen science*, Publications Office of the European Union. https://data.europa.eu/doi/10.2777/500099

European Commission: Directorate-General for Research and Innovation and Stilgoe, J., *Monitoring the evolution and benefits of responsible Research and Innovation*, Publications Office, 2018, https://data.europa.eu/doi/10.2777/285467

Kogut, P., Çelikkol, B., Vervaet, G., Schreer, O., Renault, S., Alexopoulos, C., Raes, L., & McAleer, S. (2023a). Designing citizen science tools towards increased awareness and participatory policy making for air quality: The case of COMPAIR. In Proceedings of the 18th International Conference on Environmental Science and Technology (Athens, Greece, 30 August to 2 September 2023).

Kogut, P., Raes, L., & McAleer, S. (2023b). Improving urban air quality and climate-resilience in cities with inclusive, policy-relevant citizen science. *ERCIM News, 135*, Special theme: Climate Resilient Society.

Ruston McAleer, S., McAleer, M., & Kogut, P. (2021). Forging the future of responsive cities through local digital twins. *ERCIM News, 127*, Special theme: Smart and circular cities.

Orfanou A, Vakalis S, Karelis C, Alexopoulos C, Charalabidis Y, Lekkas DF (2023) Assessing the Correlation between Citizen Science and CarbonFootprint: Introduction of COMPAIR's CO2 Calculator. Energies 16:228. https://doi.org/10.3390/en16176228

Renault, S., Feldmann, I., Raes, L., Silence, J., & Schreer, O. (2024). Dynamic exposure visualization of air quality data with augmented reality. GISTAM 2024.