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Benefits and limitations of environmental magnetism for completing citizen science on air quality: a case study in a street canyon.

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Key Points:

- Feedbacks from the participants to an air quality monitoring study carried out as a citizen science study inside a street canyon are reported.
- A magnetic air quality index (Q_{mag}) is proposed to improve communication between scientists within their community and between citizens, scientists, and elected officials.
- Benefits and limitations of the environmental magnetism technique applied to air quality measurements are discussed.
- Tips to academics for conducting this type of project, and implications on societal and political issues are documented.

Abstract

This paper details the operating experience about a case study carried out as a citizen science approach to monitor magnetic particulate matter (PM) in a street canyon in Montpellier, France. A total of 60 passive filters and 12 *Hedera Helix* pot plants were deployed in 29 households for a period of 3 months, from December 2020 to March 2021. This street canyon was chosen by the academic team because dwellers were already mobilized against the street traffic and its adverse environmental effect on air quality, and because they were in conflict on this issue with policy makers. Despite the project aimed at including all the stakeholders through co-construction, dwellers, elected officials, and staff from technical department of the city were not fully embedded. The announcement of the closure of the street to through traffic during the metrological campaign and the absence of agreement curbed their involvement and motivation. However, the feedbacks from the citizen partners promote the fact that this study

supported their claims and brought them a deeper understanding on the micro-scale air quality monitoring. Indeed, it is increasingly difficult for citizens, who seemed specifically interested in what is happening right outside their front door, to understand this measure with the emergence of ever more low-cost sensors. For that reason, we examined the citizen's degree of confidence in magnetic monitoring of air quality and how can this technique be useful in their claims. The results show that magnetism can be a measurement technique favorable to citizen participation-because it provides a large amount of data at the micro-scale of the street, while the data from the certified associations for monitoring air quality requires a spatial interpolation to map variations on a neighborhood scale. In this study, we proposed a magnetic air quality index to standardize and democratize the magnetic monitoring of air quality to facilitate the dialogue with all stakeholders.

1. Introduction

Air pollution is an environmental concern (Hopke, 2009; J. Zhang & Smith, 2003) and source of social and political conflicts (Botero, 2021; Boutaric, 2007; Calvillo, 2018; Fenger, 1999; Joumard et al., 2007). After nine years of litigation and many discussions back and forth for a positive consensus, France was finally condemned on October 24, 2019, by the Court of Justice of the European Union for persistent and systematic non-compliance with the annual limit values of NO₂ concentration in twelve French agglomerations (Boring, 2019). Despite existing regulatory frameworks as planning tools and the directive fixed in July 2017 by the French Council of State to implement strong actions, the European regulatory levels of particulate matter (PM) and NO₂ concentrations are often exceeded in French urban areas (EEA, 2021). One must note that these regulatory warning-levels are more lenient standards than the World Health Organization air quality guidelines (Hoffmann et al., 2021). Furthermore, they do not account for the ultrafine particles that constitute a serious risk to ecosystems and to human health by passing through the skin and blood barriers to accumulate in vital organs such as the lungs, heart, and brain (Elder et al., 2006; Ferin et al., 1991; Maher et al., 2016; Miller et al., 2017; Oberdörster et al., 1992, 1995). In August 2021, the inevitable happened: the French government was condemned by the French Council of State to face with a 10-million-euros fine every six months until air quality is improved.

The BREATHE project was elaborated against this background, with as common thread a citizen science approach. Studying air quality with a citizen science approach is a rapidly growing practice in recent years, as illustrated by the bibliometric study shown in Figure S1.

BREATHE aims at outlining the co-construction basis for several decision-making tools with the local authorities that have jurisdiction on air quality to reduce the social and environmental risks associated with air pollutants. This research is developed in response to a twofold expectation: from citizens on one hand and from politicians on the other. To this end, two challenges were addressed. The first was to assess the effectiveness of urban greens for monitoring, and subsequently for mitigating, the particulate matter air pollution in urban and peri-urban areas, a very dynamic research topic in scientific literature (Zupancic et al., 2015) that is increasingly making headlines in public policies (U.S. Environmental Protection Agency, 2022). To reach this goal, a non-conventional approach based on environmental magnetism techniques was used (Hofman et al., 2017). Thanks to the inexpensive and promptness of these laboratory analyses, many measurements can be carried out allowing a high spatial resolution in the monitoring. These characteristics are important for a long-term survey implemented in a citizen science model. They allow for the implementation of a scientific program over the long term by ensuring the involvement of citizens. The matter in question within BREATHE was to jointly draft with the citizens reliable mappings of Fe-bearing nanoparticles air-pollutants by means of magnetic measurements of dust deposition on plant leaves or on passive artificial filters. The first challenge was to rate the extent to which such citizen mappings can represent either a reliable alternative to mapping pollutants dispersion from numerical models as provided by the official air quality monitoring associations or at least a valuable input to complement them. The second challenge was to integrate citizens from the Citizen Science up to the Participatory Action Research (Chevalier & Buckles, 2019; Cooper, 2017) and more specifically in BREATHE case, from the monitoring of dust deposition on accumulative surfaces up to the political decision making.

To achieve these objectives, BREATHE was implemented in three test cases that were sources of conflict between citizens and policy makers: along a motorway (Letaïef et al., 2020), around a waste energy valorization center, and in an urban street canyon. The present paper will focus on the results and feedback from a part of BREATHE completed in 2021: the study carried out with and for the citizens on the traffic impact in a street canyon located in an ancient neighborhood of the city of Montpellier, France. This report is organized into four parts. After introducing the study context, we will present the materials and methods, the results, to end with a discussion around the following questions: is environmental magnetism an air quality monitoring tool reliable enough for citizens and policymakers to provide useful data to be used

in public policies? What are the effects of such approach on the actors, political governance, and decision making?

2. Study context

2.1. A street canyon environment.

The air pollution situation is particularly worrisome in urban areas where the main living and activity places for urban dwellers are typically arranged in street canyons sequences. Many studies have been carried out on the issue of air quality in these environments (see for example Lv et al., 2021, for a review). Briefly, street canyons are composed of relatively tall buildings lined up along both sides of the street, which hinder the pollutant dispersion (Jeanjean et al., 2015) and where the main source of pollutant is known to be the road traffic (Hama et al., 2017; Maher et al., 2013). Street canyons are characterized by their aspect ratio between the building height and the street width, and their symmetry. A so-called regular street corresponds to an aspect ratio close to 1, whereas a deep street canyon has an aspect ratio larger than 2 (Nicholson, 1975; Vardoulakis et al., 2003). A symmetric canyon is distinguished from an asymmetric one when buildings have approximately the same height. Understanding the pollutant dispersion as function of the geometry of the street is a major societal issue to take full cognizance of unequal burden of disease. For a few decades, many investigations were devoted to the analogical and numerical modeling of airflow and pollutant dispersion for different configurations (Caton et al., 2003; Gromke et al., 2008; Kastner-Klein & Plate, 1999; Li et al., 2019; Nazridoust & Ahmadi, 2006). It was shown that pollutant dispersion is inherently complex in street canyon due to unique micro-scale meteorological processes controlled by both the street geometry (Hunter et al., 1992; Nazridoust & Ahmadi, 2006) and the time-varying inflow (Li et al., 2019; Tominaga & Stathopoulos, 2013; Y. Zhang et al., 2011).

Saint-Louis street is in an ancient neighbor of Montpellier, a city of about 300,000 inhabitants located in the south of France (Figure 1). This area, commonly referred to as the "Arceaux", is a prime study area for assessing traffic impact in a street canyon environment. Indeed, this 245 m long and about 10 m wide street is characterized by the presence of buildings with one to four floors (from 5 m to 10 m height) and narrow sidewalks located on both sides of a single traffic lane (Figure 1). Following Nazridoust et al. (2006), Saint-Louis Street can be classified as a regular and asymmetric street canyon featuring an aspect ratio mostly of 1 and maximum 2 and differing-height buildings, respectively. The street is characterized by a continuous heavy transit traffic on the pavement of about 7000 vehicles daily and permanent

conflicts between two-wheelers users (bicycles, scooters) and pedestrians sharing the sidewalks.

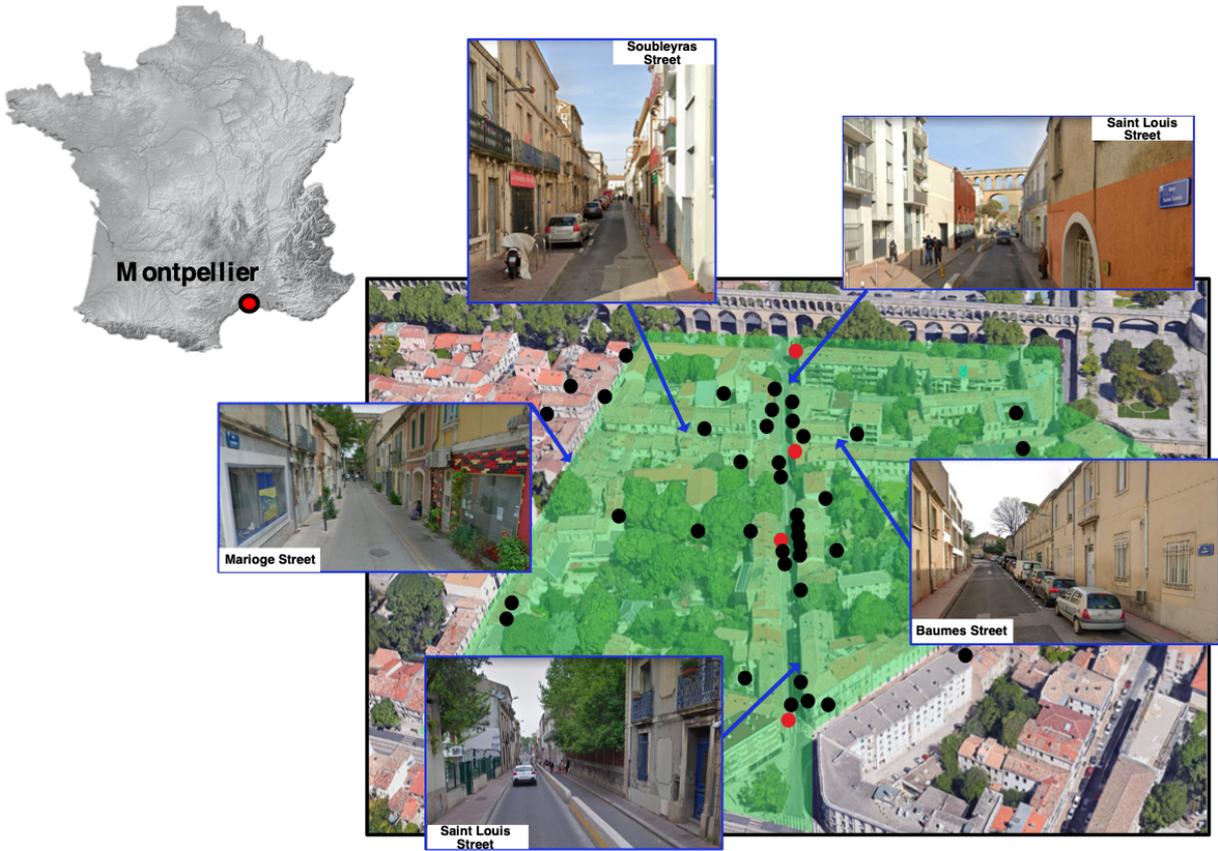


Figure 1: Location of the study area (green colored): Saint-Louis Street and its surrounding streets are in the Arceaux district, in the city center of Montpellier, France. Photographs of the Saint-Louis, Baumes, Soubleyras, and Marioge streets allow to better visualize these narrow streets where the survey was carried out. Black dots represent the different stations where the passive filters were deployed while red dots depict the temporal stations (sampled each month for 3 months).

2.2. A tri-partite research consortium.

The consortium established for this study is composed of three factions (Table 1): the academics, the citizen partners, and the metropolis representatives.

Table 1: Glossary fixed to define people involved in this study and the tools used.

<i>Terms used in this study</i>	<i>Description</i>
Academics	Academic scientists who do not live in Saint-Louis Street.
Citizen partners	Dwellers of Saint-Louis district.

Metropolis representatives	Members elected at the metropolis council and engineers from public work department.
Town hall representatives	Members elected at the town council
Participants	Group the 3 terms above-mentioned together.
Deposimeter	Combine the passive filter and <i>Hedera Helix</i> plant leaves, both acting as PM accumulative surfaces.
Device	Plan and method deployed in the Citizen Science part.

The academic task force dedicated to this study is transdisciplinary. It federated three participants from geosciences who had expertise in environmental magnetism (a senior researcher, a PhD student, and a technician), one participant from sociology (a researcher), and one participant from political sciences and science and technological studies who had expertise in Participatory Action Research (a PhD student). This participatory research was initiated by academics with a research project funded by the French National Research Agency. Within the framework of this grant, academics had proposed a program of participative sciences in which they had explained their will to involve quickly and durably the citizens in an approach of participative action research (ECSA, 2015).

The citizen partner faction is composed of dwellers of Saint-Louis district who have politicized the issue of air pollution, notably by constituting an association named “Mieux Vivre Rue Saint-Louis” which could be translated by “Living better in Saint-Louis Street”. The citizen association was consistently campaigning against the degraded living conditions caused by recurrent accidents and congested traffic. The members of the association also feared traffic harmful health impact. This fear is partly explained because they have no information on the level of pollutant emission by the local traffic in particular and by the street activity in general. This lack of relevant information is due to the absence of proper monitoring of the pollutant by an approved agency or service provider. Claiming their right to information, to live peacefully and to breathe clean air, the members of the association have been mobilized since 2017 against the town hall representatives to get an answer to their fears and expectations.

Metropolis representatives were among the actors of the project. It is important at this step of the article to specify some issues of political scale in France related to air quality. The status of metropolis was created by the French law of December 16, 2010, to strengthen the French’s territories and to affirm the role of large agglomerations as engines of growth and territory attractiveness (Griffith, 2017). The metropolises are granted powers in place of its member municipalities. The competences of these inter-communal bodies encompass the

territorial mobility as well as the protection and enhancement of the living environment, including the fight against air and noise pollution. The city of Montpellier is one of the 15 French metropolises. It acquired a metropolitan status in 2015 with the administrative grouping of 31 municipalities, which in 2019 represented a population of about 491,000 inhabitants to become “Montpellier Méditerranée Métropole”. Thus, the political interlocutors in this study are in priority the members of the metropolis council. However, the French political system remains complex. Indeed, the chair of the metropolis council being also the mayor of Montpellier, the urban governance is articulated at two scale levels on a same street. The city council has the competence of police and traffic. In total, 8 elected officials showed a real interest in this study, four from the metropolis and four from the city council, respectively. However, the involvement level of these elected officials has not remained the same during the survey.

3. Protocol and Methods

3.1. Citizen mobilization in a particular health and political context

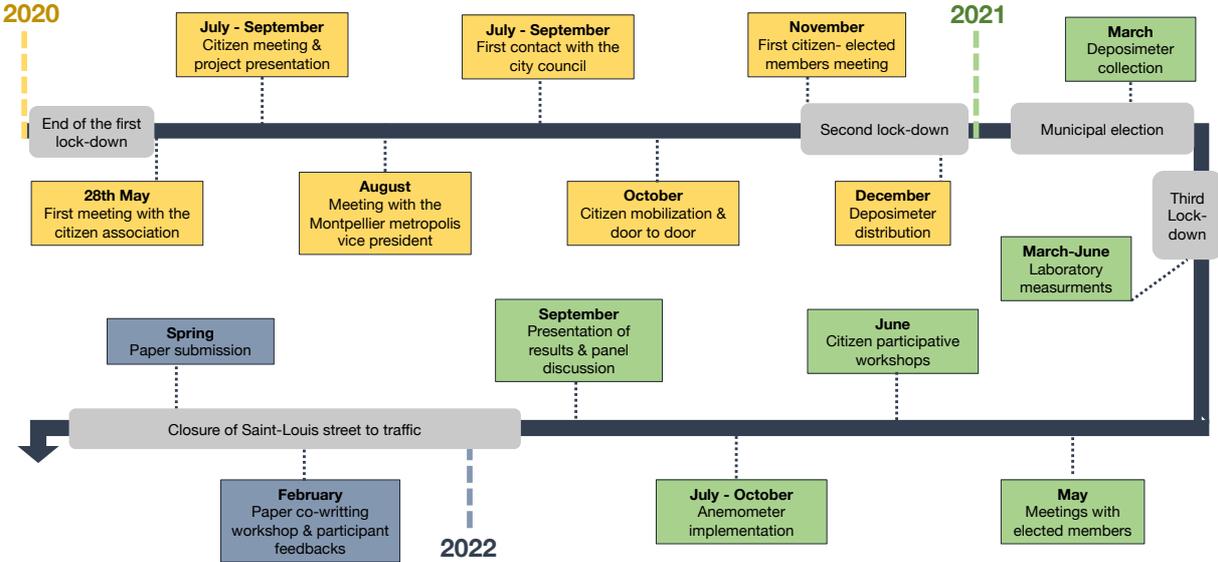


Figure 2: Timeline of the BREATHE project progress considering territorial political actions and health constraints related to the political decision during the COVID-19 crisis in France.

The Academics’ protocol was designed to reach and to involve citizens who were either members of associations (militant or not) or simple residents. It also had the objective to

integrate members of the metropolis and the city councils. This networking and construction of a group of stakeholders is the first condition for co-constructing a project that aims at meeting the needs and expectations of everyone in a win-win project. On one hand, the researchers can test their protocols and methods to evaluate the PM concentration while analyzing the scientific legitimacy regarding the quality and robustness of the analyzes. On the other hand, citizens and policy makers obtain data at a very local level that could help decision making for air pollution control. To this end, several meetings were conducted with stakeholders on Saint-Louis Street and surrounding streets (Figure 2).

The citizen implication in BREATHE began on May 28, 2020. The academics led a meeting with some members of the association “Mieux Vivre Saint-Louis”. Right after the municipal elections (June 2020; Figure 2) the academics started canvassing throughout the neighborhood. They also decided to get in touch with a second local association named “Arceaux Vie Active” (“Arceaux Active Life”). The members of this association are presumed to be favorably disposed towards the metropolis and the city governances. In addition, it is worth pointing out that the mobilization period fitted with the end of the first Covid-19 lockdown and with the municipal elections (Figure 2) implying the renewal of the metropolis council. This represents a bias in the citizen mobilization.

3.2. Experimental deposimeters deployment.

A kit to measure air pollution was distributed per household between December 3rd and 5th, 2020. The kit comprises a filter, a pair of gloves to position and secure the filter, an explanatory note (Figure 3a), and a form to be filled out (Figure 3b). This form allowed volunteers to provide researchers with accurate information about the location, the date, and the time of filter placement and removal. Most of the filters were set up for 3 months, from December 5th to March 5th, 2020, except for few stations that were sampled each month (red dots in Figure 1) during the 3-months establishment.



Figure 3: [a] Extract from the protocol designed to facilitate the deposimeters set up by the inhabitants. [b] Protocol presentation and explanation during the kit distribution. [c] Examples of the settled filters pictures sent by citizen partners.

The passive filter design was worked out to be easy to set up and to be positioned outside during the winter season. Paper filter of 2–3 μm particle retention was chosen as an accumulating surface. To prevent mechanical weathering by insects or water saturation by rainfall that could have reduced their filtering surface, they have been inserted inside the mounting design proposed by Cao et al. (2015). The assembly was composed of a plastic electrical box of a circular section of 50.6 cm^2 in which filters were placed between two layers of washed natural wool to absorb excess moisture. The whole was closed by a piece of 1 mm mesh canvas allowing only the entry of fine particles (Figure 3a). In addition to the passive filter devices, twenty *Hedera Helix* pot plants were distributed and placed on balconies. We chose *Hedera Helix* because it is a robust plant resisting to the winter temperatures and that does not require a particular maintenance. At the end of the three months of exposure, we took some leaves for analysis and offered the pots to the volunteers as a memento of their participation. To simplify the writing, we combined hereafter the passive filter and *Hedera Helix* leaves acting as accumulative surfaces in a single term: deposimeters (Table 1). Once the deposimeters were installed, the citizen partners sent a picture of them in situation (Figure 3c) with the filled form to the coordinator.

3.3. Magnetic measurements.

Magnetic monitoring is increasingly used as a proxy of PM deposition on accumulative surfaces (Hofman et al., 2017; Maher & Thompson, 1999). It consists of studying the magnetic properties of such surfaces after they have been exposed to a polluted air. Many studies have already shown the correlation between magnetic properties of Fe-bearing nanoparticles with both traffic-related PM concentrations (Hofman et al., 2017; Letaïef et al., 2020; Matzka & Maher, 1999; Rea-Downing et al., 2020) and trace metals concentrations such as Pb, Co, Ti, Zn, Sr (Hofman et al., 2014, 2020; Lu et al., 2016). It is also important to mention that Fe-bearing nanoparticles are ubiquitous, especially in urban PM (Thorpe & Harrison, 2008), and easy to detect because they show a ferromagnetic (*sensu lato*) signal (Gonet & Maher, 2019).

Magnetic measurements were performed in the laboratory following two steps. Prior to the deployment, a blank correction was achieved. For that, an Isothermal Remanent Magnetization (IRM; see e.g., Tauxe et al., 2018 for further physical explanations) was imparted at 100, 300, and 1000 milli-Tesla to all pristine filters and few leaves collected from each *Hedera Helix* pot associated to their respective sample holders (8-cm³ plastic cubes), with the impulse magnetizer ASC Model IM-10-30 from ASC Scientific, and then measured with a 2G-SQUID cryogenic magnetometer. Note that the *Hedera Helix* pot plants were bought the same day in the same nursery. Before the blank measurement and their deployment in the street, we took care to clean all the leaves with purified water. Because we are not able to magnetize the samples without magnetizing their plastic cubes, these steps are required and allow to subtract in data reduction the signal of potential magnetic impurities which may be present in the pristine filters, plant leaves, and in the sample holders. After the 3-months exposition to pollution in Saint-Louis Street, these operations were repeated for each sample. In data reduction, magnetic moments expressed in Am² were corrected by subtracting the magnetic moment of blank samples and then were normalized by the filter or leaves areas in m², yielding the IRM intensities in Ampere (A).

Furthermore, IRM intensity may be subject to instabilities due to the magnetic viscous effect of variable relaxation times (Néel, 1949) if sufficiently small magnetic nanoparticles are present as often observed in magnetic monitoring survey (Letaïef et al., 2020). As it is routinely done in our laboratory, samples were placed in a zero-field following the IRM acquisition until the magnetization was stable enough. We checked the stability of the 1000 mT-magnetization imparted to the empty and to the filled sample holder and found a very small magnetic viscous

effect characterized by a relaxation time lower than 2 and 10 min, respectively. Then, the duration of stay in zero-field following the IRM acquisition and prior to the measurements was set on a conservative basis to a minimum of 15 min for all samples.

3.4. Citizen Science and Participatory Action Research.

Citizen Science is characterized by a wide range of practices developed in the last decades (Strasser et al., 2019). Consequently, it remains difficult to clearly define it (Eitzel et al., 2017; Haklay et al., 2021; Heigl et al., 2019). Citizen Science needs to be considered as a real research field and not only as an opportunity for greater public engagement or democratization of science (Göbel et al., 2021). Citizen science must control internal and external biases with a critical reflexive approach and by facing epistemological challenges of interdisciplinarity (Bedessem & Ruphy, 2020). The main challenges involve assessing:

- the scientific legitimacy on the quality and robustness of the analyzes produced (Bœuf et al., 2012; Irwin, 2001; Strasser et al., 2019),
- the political and social shifts in the citizen empowerment (Bela et al., 2016; Bonney et al., 2016; Kieffer, 2014; Ottinger, 2010),
- the effectiveness of the actions on the environmental issues (Brossard et al., 2005; Kythreotis et al., 2019),
- the ethical compliance regarding both the social categories mobilized in this type of participatory mechanism (Riesch & Potter, 2014) and the theoretical reference framework (Grainger, 2017).

To address these challenges, a participatory engineering tool developed by one of us was implemented: Artivists-Atelier (AA)-device (Dosias-Perla et al., 2018). Of course, AA-device could be complemented by classical enquiries. It enables to intervene at all phases of the citizen actions: the mobilization and the training of the citizen for the Citizen Science program, the co-producing action plans on air, and the co-building of decision-making tools from participative workshops with all stakeholders including officials. It was designed to support public policies, decision-making, and citizen needs and expectations.

This device is in line with the work on the sociological Habermas-Mouffe debate (Kapoor, 2002). The theory of deliberative democracy developed by Habermas is based on a rational consensus, whereas the theory of agonistic democracy developed by Mouffe allows for the expression of alternative positions and voices (Beaumont & Nicholls, 2008). Many authors,

in French research refer to a "participative turning point". In this context many democratic experimentations have tried to develop democratic governance for social and environmental issues (Bevir, 2010). Considering this, the AA-device enables to analyze at once (i) the changes in the subjective representations of the participants, the knowledge, the speeches on air quality and the participatory democracy, (ii) the sharing of the decisional and symbolic power in the participatory workshops, (iii) the contribution of the citizens in the participatory workshops (we can talk about empowerment), and (iv) the public action on the air quality.

On a critical and reflexive way, one has to examine the purposes and the ethics of the system that it necessarily disrupts (Dewey, 1927). It is worth pointing that academics have to treat carefully bias toward the current political situation or the citizen claims. Ideally, to reduce distortion, a good participatory action research practice is to ask for a partnership agreement between all the stakeholders. This agreement allows all the stakeholders (officials, researchers, citizen and associations in our case study) to define their role and make possible to develop a participatory approach. This research posture is a normative choice that strengthens the effects of the project on local participatory democracy. The Research component in the AA-device is therefore designed for: (1) going through the process of institutionalization of the research project as far as it is possible by contracting an agreement and (2) developing a permanent critical and reflexive analysis to objectify benefits and limits of the citizen research project. The Participation component in the AA-device is designed for analyzing the citizen empowerment with the actors' posture and citizens' role in the construction of public action. To this end, the participation was developed in three stages. The first was to identify the expectations and needs of all the actors. The second step was to draw up a field inventory, as exhaustive as possible. The third step aimed at designing and facilitating participatory workshops whose constructs were analyzed by the researchers. The Action research component in the AA-device made possible to study the direct and indirect effects of the project on decision-making and on the posture of the actors involved in the project and in the public decision on air quality.

Finally, following "The ten principles of Citizen Science of good practice" defined by the European Citizen Science Association (Robinson et al., 2018), it is possible to identify several Citizen Science and Participatory Action Research observable parameters to analyze the participatory workshops. They particularly allow measuring: the level of citizen contribution and involvement, the quality of scientific outcomes, the level of collaboration between the participants, the common benefits collected, the influence on policy makers and public action, its effectiveness and all other effects and actions carried out by non-institutional

actors. First, the academics interviewed project participants after presenting them the metrics results. Second, the researchers facilitated a participatory workshop with these same volunteers. This workshop was designed to get their feedback on the project, to check if the project met their expectations and to know if their representations and knowledge on the issue of air quality have evolved during the project and if so if the project has contributed to it. To do this, the participants ranked themselves on a metric scale from 0 to 10 according to their respective experience in response to a list of questions (Table 2). Finally, academics asked the question: Based on your own experience, if you were to participate in a new similar project, what would you change to improve it?

Table 2: Questionnaire during reflexive and critical participatory workshop

#	Theme	Question
1	Expectations	How did the BREATHE project meet your expectations?
2	Interests	What is your interest in the BREATHE project?
3	Commitment	What is your level of involvement in the BREATHE project?
4	Enjoyment	What is your level of enjoyment in participating in the BREATHE project?
5.1	Air quality measurements knowledge	Did the BREATHE project provide you with knowledge on: measuring air quality?
5.2	Health knowledge	Did the BREATHE project provide you with knowledge on the health impact on air quality?
5.3	Decision making knowledge	Did the BREATHE project provide you with knowledge on decision making mechanisms?
6	Means to act	Do you think that the project has been a lever for solving problems in the neighborhood?
7	3D model workshop	Did the participatory workshop (3D model) of June 7, 2021, make it possible to influence public action within the framework of the "peaceful neighborhood" consultation?
8.1	Collaboration with researchers	What is your level of collaboration with researchers?
8.2	Collaboration with elected officials	What is your level of collaboration with elected officials and their service?
8.3	Collaboration among residents	What is your level of collaboration with other residents?
8.4	Collaboration with users	What is your level of collaboration with users?
9.1	Metrology protocol	What is your level of understanding of the research protocol regarding participatory metrology?
9.2	Appropriation of results	What is your level of ownership of the results presented?

9.3	PAR protocol	What is your level of understanding of the research protocol for participatory action research (PAR)?
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4. Results

4.1. Project institutionalization phases.

4.1.1. Building of the consortium.

Twenty-nine family homes that have been approached during the mobilization phase joined the project allowing the deployment of 72 deposimeters distributed in the balconies. This citizen partner group was globally representative of the Arceaux neighborhood with 75% inhabitants, 25% professionals in their workplace, 55% women, 45% men, 10% less than 26 years old, 75% between 26-64 years old, 15% more than 64 years old, 65% of executives and higher intellectual professions, 14% retired, 7% employees, 10% students, and 4% of unemployed people. This low number of family homes mobilized regarding the size of the neighborhood might be correlated with the regulatory constraints limiting social gatherings in response to unusual sanitary conditions associated with the COVID-19 pandemic (Figure 2). Given our feedbacks from previous citizen research projects, the citizen partners gauge should have been greater, let say about fifty family homes, and more diversified concerning ages, socio-professional categories, and genders. In addition, the electoral process is an important contextual element to fully understand and analyze the posture and positions of citizens in the project (Figure 2). Despite their moderate number, the volunteers' involvement was intense during the municipal election. Indeed, during this period, the members of the association "Mieux Vivre rue Saint-Louis" posted messages (around a thousand) on social networks about the BREATHE project. Saint-Louis street was politicized by most of the electoral campaign candidates, who promised to implement strategies toward a clean air and a better living environment.

4.1.2. Integration of the Montpellier officials:

Academics first met the metropolis vice-chair in charge of research, development, and innovation at the university premises in August 2020. The project was very well received and is still supported by this leading personality. In November 2020, a videoconference was held between the research consortium (academics and citizen) and the metropolis vice-chair in charge of nature and biodiversity due to the impossibility to meet physically during the pandemic. This meeting aimed at preparing the citizen metrology campaign and questioned the

dwellers on their vision of the future ideal neighborhood. In January 2021, the vice-chair of the city council in charge of the city center, who was also the former AVA citizen association vice-chair, contacted the academics to express his concern over the survey and to obtain more details. Notwithstanding he showed a genuine interest, he decided to stay in a wait-and-see attitude. Finally, a new meeting was held in October 2021, with the metropolis vice-chair for the transport and active mobility, the metropolis vice-chair for the environment, and people from the city technical department. This meeting was about organizing the interplays between the metropolitan institution and citizen science surveys. It led to a positive outcome: a free of charge booth was proposed to the Saint-Louis street research consortium at the urban green festival held in the pedestrian city center. The objective was to highlight the project and to develop a democratization on air issues. This was a crucial stage in the project institutionalization. During the festival, academics finally met the metropolis chair at the booth for a long and fruitful discussion about the project for which he was surprisingly unaware of its existence. However, he showed a particular interest by calling his own services to get in contact with the academics. On their demand, the latter wrote a note to extend BREATHE approach in several other place in Montpellier and the surrounding cities and villages included in the metropolis. The discussion is still currently ongoing. To this end, academics conducted a series of meetings with the metropolis vice-chair in charge of transport and active mobility, in February 2021, and another with both its namesake appointed on environment and the deputy of peaceful and breathable city in March 2021.

Right after the deposimeter withdrawals in March 2021 academics organized with the collaboration of the Council for Architecture, Urban Planning, and the Environment (CAUE) a meeting, as requested by the vice-chair in charge of mobility. This meeting aimed at presenting the BREATHE project approach and to discuss on a tri-partite agreement between the participants. Three metropolitan chair-advisors attended to this meeting including who is appointed on “democratic renewal and social innovation”. During this meeting, one citizen partner expressed the importance “to contract an agreement to make sure the citizen work would be taken into account”. The municipality team did not give effect to this request because of the too restrictive nature of the agreement. As a matter of fact, the vice-chair appointed on democratic renewal and social innovation mentioned that: “the request for an agreement caused discomfort to a part of the metropolis council” because they were not able, with the town planner in charge of future developments, to conduct alone the concertation with inhabitants. This reaction is clearly one of the major outcomes for this study. Taking in a critical and

reflexive loop, this result was the subject to further investigations. It appeared that this decision of how to lead the concertation was a municipality choice. This identified limit is circumscribed at a local scale.

4.1.3. The closure of Saint-Louis Street announcement.

Right after the beginning of the filter deployment campaign in December 2020, the newly elected metropolis chair decided to close Saint-Louis Street to traffic. Although it is difficult to analyze his decision as a direct or indirect effect of the project, the citizen partners are convinced that the project provided a great help. Shortly after, following the first exchanges with the AVA association, a participatory cartography of future development of the Arceaux neighborhood was organized in February 2021 during a market day to involve as many residents as possible. This enabled to introduce a part of the participatory tools, provide a quick overview of the inhabitants needs and expectations, and finally to obtain a cartography on the propositions of citizen’s actions. Then, the town hall representatives initiated a citizen consultation named “peaceful Arceaux neighborhood” following their promises for democratic renewal. To this end, six dwellers chosen by random draw took part in a participatory workshop in June 2021 based on discussions from a special 3D mockup of Saint-Louis Street made for the occasion (Figure 4a).

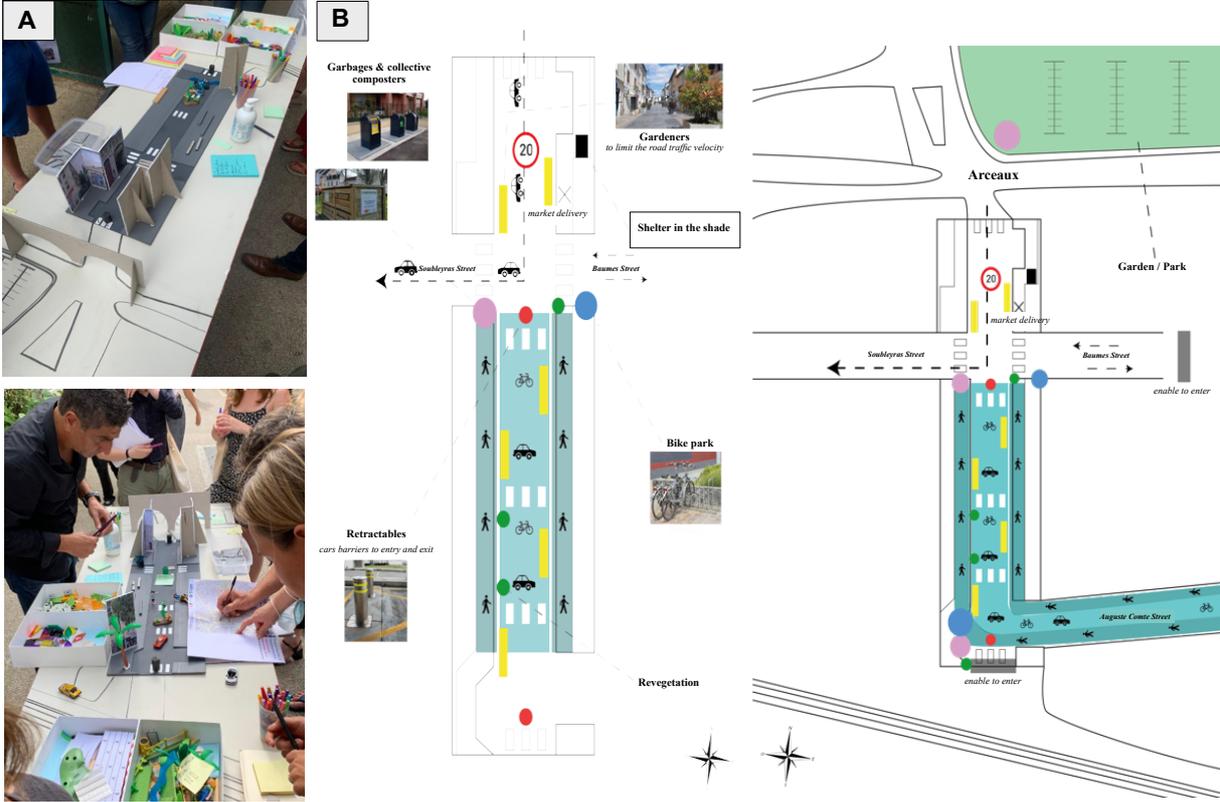


Figure 4: [a] Arceaux neighborhood scale-down model especially made for the participatory workshop. [b] The ideal Arceaux neighborhood conceptualized by the citizen partners.

This workshop aims at making a synthesis of dwellers' propositions (Figure 4b) and to support the citizen partners in the conceptualization of the potential neighborhood arrangement idealized by their own thoughts. The idea would be to influence the decision making. As we wrote this report, the citizen consultation was still in progress. The overview (Figure 4b) was sketched by the academic team to guide inhabitants during the consultation phase led by the metropolis representatives. It is important to mention that the inhabitants are the first experts of their living environment. Unfortunately, this co-produced work was not published by the metropolis representatives in the citizen consultation dedicated website. This result is particularly interesting since the mockup was drawn up based on the expertise of the inhabitants and accompanied by means of a scientific tool developed by the academics.

4.2. Magnetic mapping of traffic-related Fe-bearing nanoparticles.

As it was mentioned above, air pollution refers to many sources. Therefore, following the citizen expectations, its assessment was directly focused on the rating of the local traffic source. For that, it seems inescapable to emancipate from the other potential PM sources and thus the regional background level. The solution is to use the relative concentrations of Fe-bearing nanoparticles expressed as a relative change (RC) of the IRM intensity (Letaïef et al., 2020):

$$RC = \frac{IRM_{traffic} - IRM_{reference}}{IRM_{reference}}$$

where $IRM_{reference}$ is the background IRM intensities measured from samples collected at a monitoring site not associated with the local traffic source. The location of the reference deposimeters and their positioning is essential in our approach. Here, we selected peri-urban areas in the north of the city, more specifically in backyards of family home located in residential areas that are not directly in contact with urban traffic. The results are presented in Figure 5.

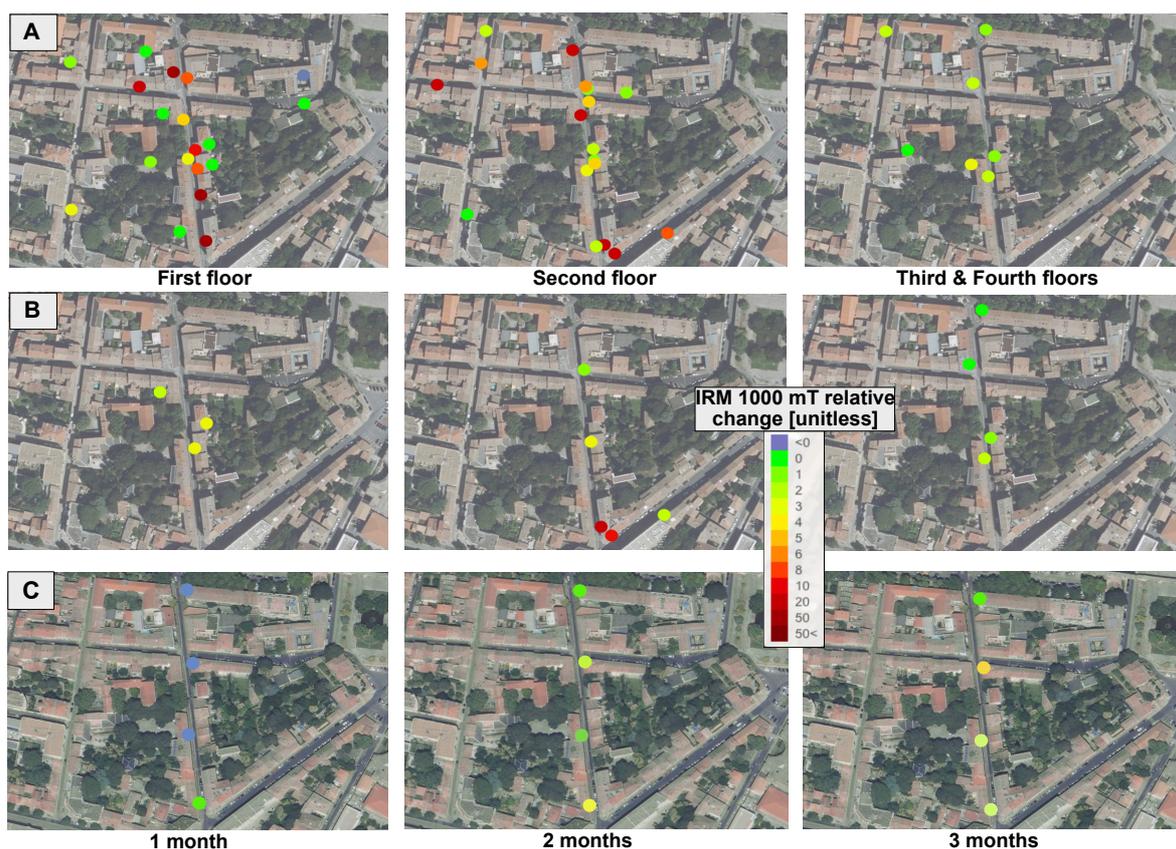


Figure 5: Spatial magnetic mapping measured in Saint-Louis Street and its adjacent streets by the relative change of traffic-derived PM concentrations for [a] passive filters. [b] *Hedera Helix* plant leaves. [c] Gradual time exposure measurements performed on passive filters. The color scale from green to dark red in an ascending range from 0 to 50 and upper indicates increases of relative concentration for PM deposition and thus makes clear the PM concentration enrichments compared to those measured at the reference stations. Data are supplied in Tables S2 to S4.

First, a clear pattern emerges from spatial magnetic measurements both for artificial filters (Figure 5a) and *Hedera Helix* leaves (Figure 5b). Lower values are found for balconies located higher in the buildings, indicating that Fe-bearing nanoparticles from traffic tend to stay close to traffic lanes. The inhabitants were able to directly apprehend a result in line with scientific knowledge for this type of environment (Caton et al., 2003): the ones located on the top floors of the buildings are less exposed to the pollutants released by the road traffic than those located at the ground floor. This trend is most clearly illustrated in Figure 6. To strengthen this observation, we computed unpaired two-samples Wilcoxon tests to compare the distributions of the relative change parameter between floor levels. After having taken care to exclude from this analysis the data of the deposimeters located in the backyards and thus that are not in direct contact with the traffic, we can conclude at a 5 percent significance level that : (i) for the paper filters, the street level (i.e, first floor) median RC value is not significantly

greater than the second floor median RC (p-value = 0.1426) but it is greater when compared to the one of the 3rd and 4th floor combined (p-value = 0.0085); The second floor median RC value is also greater than the one of the upper levels (p-value = 0.0146). (ii) for the *hedera helix* samples, the second floor median RC value is significantly greater than the one for the upper floors (p-value = 0.0318). As evident from Figure 5, the magnetic mappings display variable Fe-bearing nanoparticles relative concentrations at the housing scale, but no specific trends are found along the streets. This brings a source of complexity in the citizen analysis. Furthermore, we note that the pattern given by *Hedera Helix* leaves measurements (Figure 5b and Figure 6) is comparable to the one given by the artificial filters. This result strengthens our approach based on magnetic monitoring of dust deposition on accumulative surfaces.

As illustrated in Figure 5c, we can observe a gradual increase in the values of IRM_{1000mT} relative variation as the exposure time of the deployed filters increases. These results reveal a progressive enrichment in pollutant of about twice greater between the first and the second month and up to 3 to 5 times more during the third month of exposure, and this whatever the location of the dwellings.

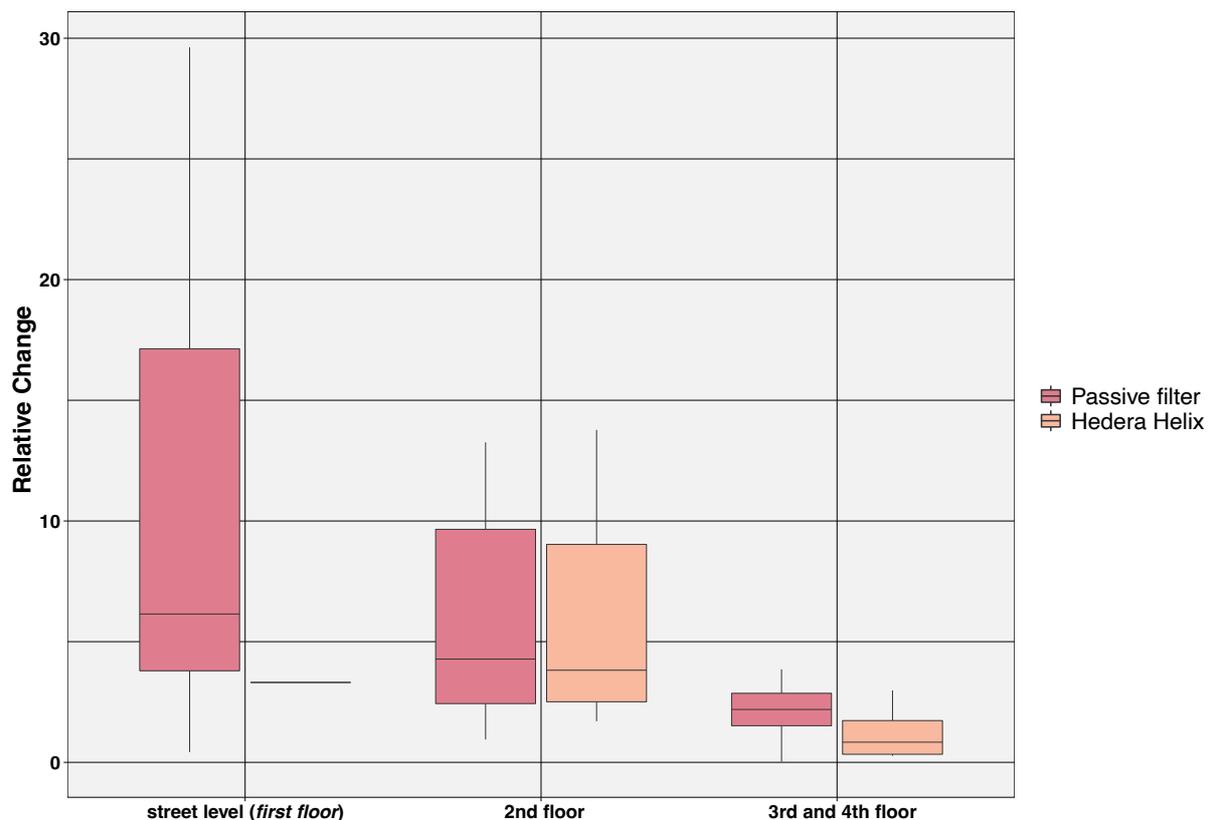


Figure 6: Distribution of the Relative Change values as function of the floor levels. Data obtained from depositometers located in backyards, i.e., that are not in direct contact with traffic, are excluded from this analysis.

Finally, to get a better understanding on the nature and composition of Fe-bearing nanoparticles collected, we calculated the relationship of $IRM_{100\text{ mT}}$ or $IRM_{300\text{ mT}}$ with $IRM_{1000\text{mT}}$ values. The ratio between both values is expressed as a pseudo-S-ratio (Figure 7). Values close to 1 indicate a magnetic saturation already reached at 300 mT, which means that there is a presence of a magnetic mineral easily magnetizable (soft magnetic mineral) often associated to the presence of magnetite-like material. Values close to zero indicate the presence of hard magnetic mineral such as hematite. Here, it appears that the magnetic saturation is reached at 300 mT allowing us to conclude that the remanence of the PM traffic-related is dominated by the presence of magnetite-like material, possibly oxidized to maghemite.

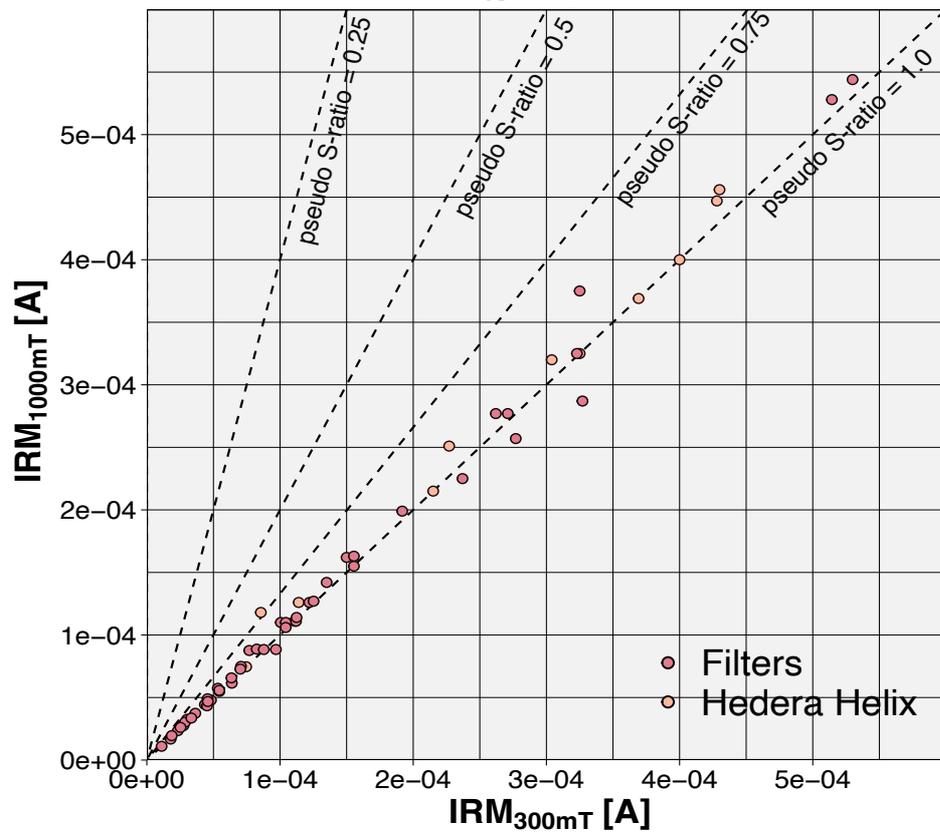
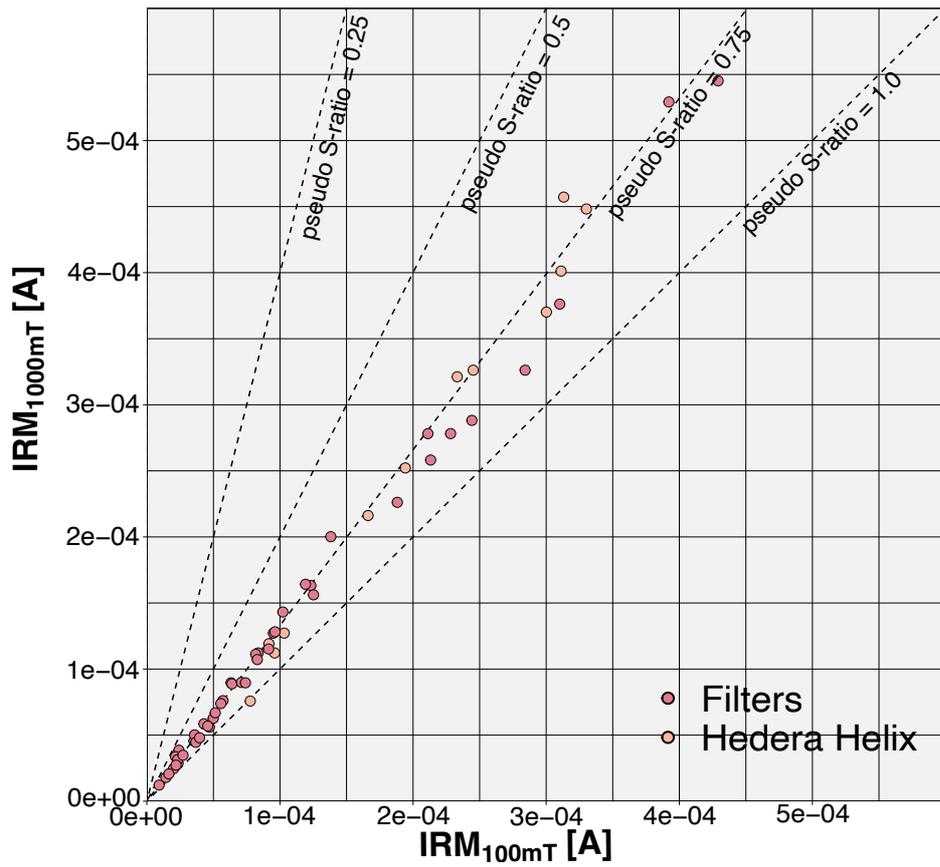


Figure 7: Correlation between IRM_{100mT} and IRM_{1000mT} (upper plot) and between IRM_{300mT} and IRM_{1000mT} (lower plot) for passive filters and *hedera helix* leaves settled on the balconies of Saint-Louis Street. Four constant values of the pseudo-S-ratio are

illustrated with dashed-lines to help the interpretation. Note that pseudo-S-ratio values greater than 1 as observed for some samples in the lower plot are theoretically impossible to explain. We believe that this is a measurement error problem in the present case. Data are supplied in Tables S2 to S4.

4.3. Critical and reflexive feedbacks

4.3.1. First outcomes during a public presentation

The academics organized in September 2021 a presentation of the first results in the coffee shop “Le Gazette Café” in downtown Montpellier and a round-table discussion with two non-partner academics working on public health related to air quality, a citizen partner, a representative of a bicycle user association “Vélo Cité”, the metropolis vice-chair appointed on environment, a representative from the state-approved air quality measurements agency (ATMO-Occitanie), and the academics. Following the round-table discussion, about 30 citizens participated to a very fruitful debate. However, except the only representative citizen partner, none of the citizen partner group member came to this event. The citizen partners commitment to the project appeared clearly weaker after the street closure announcement than at the beginning.

4.3.2. Critical and reflexive participatory co-writing workshop

To analyze the limits and benefits of the BREATHE approach, a critical and reflexive participatory workshop was organized in February 2022 as a co-drafting process. The protocol remained in the hands of the academics. The first part of the workshop was dedicated to a presentation of the magnetic cartography results (Figure 5) and discussions. The discussion first focused on a period of the study when the street had less traffic, *i.e.*, during the lock-down due to COVID-19. Then, the discussions were focused on the added value and the interests of having a high-definition mapping of the pollutants. We were also able to discuss the limits of this map. Indeed, it would have been interesting to have more committed citizens which would have allowed for more samples. The second part of the workshop was reserved for critical and reflective questions. The researchers asked a series of questions for the participants and themselves to answer. These questions were focused on their feedbacks (Table 2). Overall, we found a great heterogeneity in the responses, except for those concerning interest in the project and the understanding of the metrology protocol (Figure 8). The results of this workshop highlight that: (1) questions on metrology and the need to support public action are scored higher than the others - (2) contributions on knowledge were very limited - (3) collaboration

was easier with academics than with elected officials - (4) expectations and support for decision making were important for participants (Figure 8).

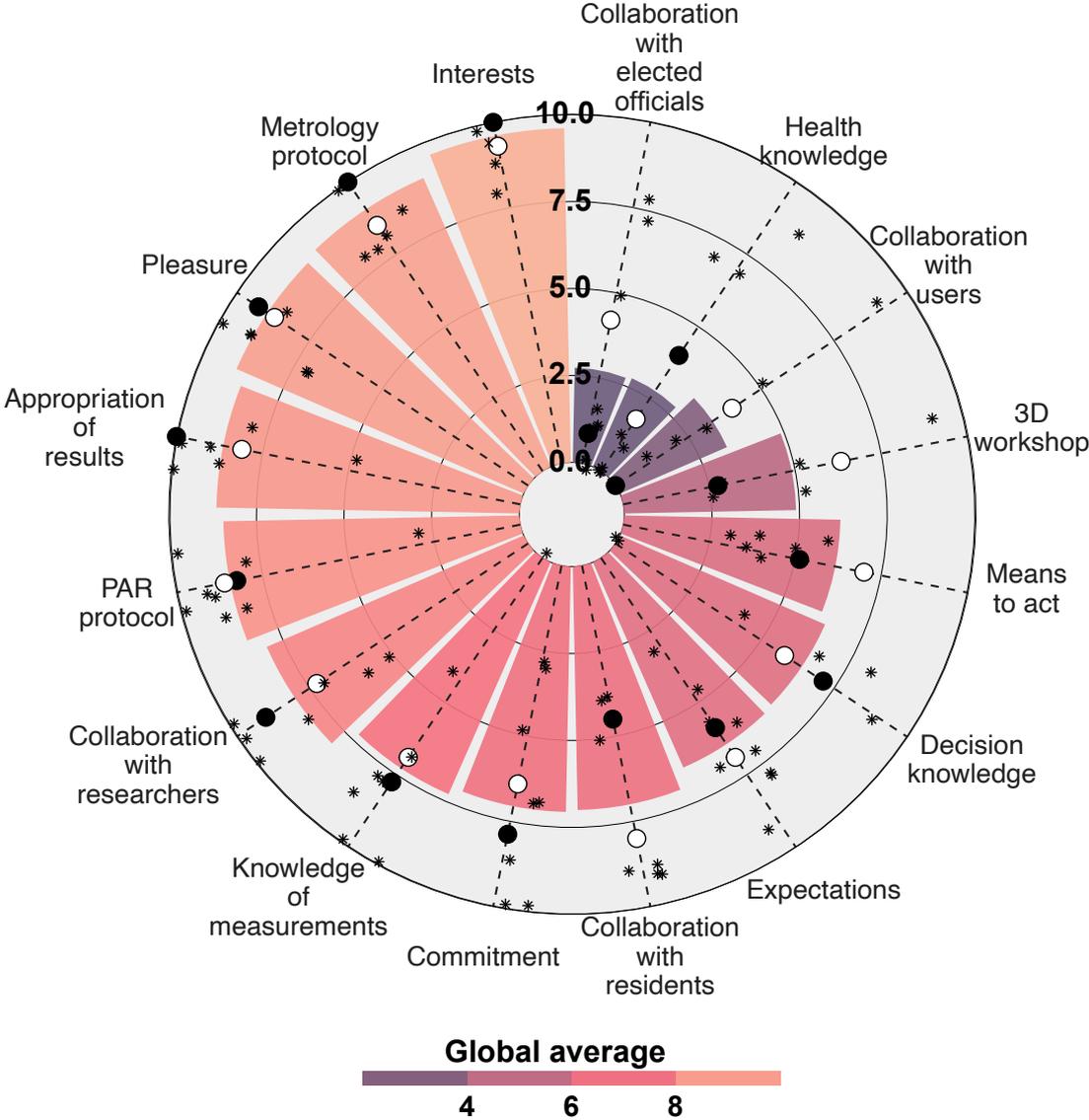


Figure 8: Representation of the participants and academics positioning by theme. The global average by theme is illustrated by the color scale of the radar plot. Filled dots and empty dots are the average for academics and citizen partners, respectively. The stars represent the bulk data. Note that answering was not mandatory and participants may withhold their positioning. Data are supplied in Table S5.

The final question of the workshop was, "If you were involved in a similar project again, what would you change to improve the project and your participation?" A citizen partner of the association "Mieux Vivre Rue Saint-Louis" answered by reporting that some of the inhabitants' group feared instrumentalization by the academics. It would seem, after further discussion, that the problem lies in a lack of understanding of the researchers' objectives and

their research questions. They were also doubtful that this research work (mapping, policy support, training) was free of charges for the citizens. Another citizen added: “I saw the project as academic research and that was enough for me. It would be useful to obtain a little more collaboration with the town hall representatives and maybe that will come”. Another citizen partner outbid by saying that “he would like to involve more inhabitants”.

The metropolis and the town hall representatives did not come to the workshop. We had some assumptions about their absence. We later learned that the same day at the same time and at the same place (the CAUE), the vice-chair delegated to the city center tried to organize a meeting for completion of the democratic renewal process. The CAUE director decided not to cancel the workshop organized by the academic team despite the town hall representative’s demand. The academics were not invited to participate at this metropolitan meeting held elsewhere. After further investigations we learned that the municipality meeting was very conflictual because the municipality team did not take enough into account the citizen propositions at first.

Finally, right after the participatory workshop, one of citizen partner e-mailed the metropolis chair and asked him to participate to the BREATHE project and to the writing of the article. The chair mailed back and assured he wanted to get in touch with the academics because “the choices that illustrate the improvement in air quality must be highlighted”. Thereupon, academics still have received no correspondence from the chair even if this one has the phone number of the PhD student on political sciences.

5. Discussion

5.1. Magnetic measurements: uncertainties and relevance of the method.

Magnetic monitoring of traffic-related Fe-bearing nanoparticles performed on passive filters and *Hedera Helix* leaves (Figures 5a and 5b) demonstrates similar trends with a decrease of PM relative concentrations as the apartments are higher in the buildings. On the contrary, no specific trend is found at the street level. This result could be explained by the street geometry and the variation in height of buildings, which foster the creation of vertical motion and up to four vortices might appear within the canyon cavity (Nazridoust & Ahmadi, 2006). Another parameter to think about in these interpretations is the time-varying inflows. In this case study, the prevailing wind direction, measured with an anemometer installed on the aqueduct located at the beginning of the street, is parallel to the street direction (Figure S2). A fact that goes

against usual investigations found in the literature where the prevailing wind is perpendicular to the street canyon. It must be emphasized that the data from the anemometer is of poor quality because this instrument was protected to the West and to the East by the aqueduct arches. In addition, temporal measurements (Figure 5c) show each month a gradual accumulation of traffic-related PM during three months in which the deposimeters have been deployed in the streets, as expected for accumulative PM deposition surface. These results provide a better understanding of the spatial and temporal variations of pollutant deposition in a street canyon. The magnetic method seems to be precise enough to detect small variations at the street-level scale and this, whatever the nature of the deposimeters (plant leaves or filter). The academics think important that when setting up at the start of the survey, deposimeters must be as clean as possible for adequate metrological comparability of PM concentrations. Otherwise, the signal could be biased by a re-emission of pre-existent PM by wind or rain, for example.

The interest of this non-conventional technique has greatly increased during the last decades (Gonet & Maher, 2019; Hofman et al., 2017). First, correlations between chemical compositions and various magnetic parameters have been already made. For instance, a study shows meaningful associations between Saturated Isothermal Remanent Magnetization (SIRM) parameter measured on plant leaves with the traffic-related Pb concentrations despite the fact that leaded fuel has been forbidden in Europe since 2000 (Maher et al., 2008). Next, Castanheiro et al. (2020) measured the magnetic signature and element content of the accumulation of atmospheric dust depositions on leaves collected every three weeks. The accumulation was observed visually by microscopy and detected magnetically, while the metal enrichments were not obvious. Finally, a recent study compared the IRM_{1000mT} relative changes values with a numerical modeling for $PM_{2.5}$ dispersions along a motorway (Letaïef et al., 2020). The strengths of this model based on computational fluid dynamics (CFD) with the Reynolds-Averaged Navier–Stokes (RANS) equations is to consider the traffic-induced momentum and turbulence. Even if the model can be improved by adding the contribution of plants to remove PM from the air, the results are truly encouraging. Indeed, the PM concentration follows trends forecasted by the techniques of environmental magnetism.

For all the reasons mentioned above, the research assumption that magnetic monitoring can be considered as a possible alternative or complement to state-approved air quality measurements is being increasingly reinforced. Moreover, because it is a rapid and low-cost method, considerable amounts of measurements can be made. It promotes the implementation of studies in the form of citizen science where the citizen is involved on the entire construction

of the data, from the acquisition, the analysis up to the interpretation. By understanding the data, it is easily accepted by the citizens. On the contrary, the conventional measurement stations are often sparse at the city-scale and therefore their data needs to be interpolated by modeling to obtain the spatial variations at the scale of the city. Such modeling is in most cases difficult for citizens and decision makers to apprehend and therefore can be misunderstood and thus can fuel social conflict. Considering that magnetic method is efficient at micro-scales, it can therefore be helpful in turn for the state-approved air quality measurements agency to help in calibrating their modeling.

Since January 2021 the national air quality monitoring agency introduced an air quality index (Table S1) integrating different pollutants such as the PM (PM_{2.5} and PM₁₀), the NO₂, the ozone (O₃) and the SO₂ concentrations. This index characterizes the one-day global air quality for a spatial scale deemed representative for each municipality. It is calculated from the mesoscale modeling points included in the perimeter of the municipality. Finally, the retained index is the most degraded point of the municipal grid. Simultaneously, since an increasing number of studies care about air pollution monitoring through a magnetic approach, the implementation of a magnetic air quality index (Q_{mag} ; Table S1) could facilitate the communication between academics, elected people, and citizens, as well as between researchers from the same field. For this reason, we propose a magnetic index based on the IRM relative change values (Table S1). This tool is even more legitimate since we measure the local source-specific pollution with the relative change. Thus, this measurement method could easily supplement the governmental agency measurements by improving the data at small spatial scale. The magnetic index could be progressively refined later by the community by notably integrating the nature, the magnetic characterization of the pollutant sources but also their grain-size and harmfulness. The smallest Fe-nanoparticles (between 3 and 30 nm), which are the most dangerous for health, are easily detectable in magnetism laboratories thanks to their superparamagnetic behavior. Based on Néel relaxation theory (Néel, 1949), this behavior can be quantified in different ways (Tauxe et al., 2018).

Nevertheless, this method has its limits. Because all the traffic-related pollutants are not necessarily magnetic, one may wonder what we are truly measuring. For this reason, it appears necessary to magnetically determine the different traffic-related sources and then, their contributions by means of a source-to-sink approach (Letaïef et al., 2022). In addition, environmental magnetism investigations aim at determining the magnetic mineralogy, the grain size, and the concentration of magnetic material. To do so, it is needed to carry out a whole

battery of analyzes that could be time-consuming and difficult to put through. For example, the pseudo-S-ratios calculated here for most of the PM collected are close to 1 (Figure 7), suggesting a dominance of low coercivity material such as magnetite. Considering that, the magnetic signal could be dominated by abrasion products like brakes (Ingo et al., 2022). Further analyses reveal that brake pads are highly magnetized, with low coercivity and not mainly composed of magnetite but also ferrite or other materials that could not easily traceable with the analytical means available in rock magnetism laboratories (Figure S3).

5.2. Contributions and limits of the BREATHE project on social and political issues.

The integrative methodological approach used in this study provided relevant results in terms of methodological, epistemic, researchers' posture, and public action. However, the discussion will be strictly limited to two points which appears to be the most relevant: (1) the contributions and limits about air citizen monitoring and decision making and (2) the epistemological and analytical perspectives.

The study on Saint-Louis Street permits to support the inhabitant claims, as highlighted in the workshop by one resident. Nonetheless, the project is still in progress and according to the different changes that will be operated after Saint-Louis Street closure, the stances of the different actors might yet change. As previously documented, the magnetic method applied to air quality monitoring displayed its efficiency at micro-scale. Besides, it could be an effective tool to complement information given to the community through the formal channels such as ATMO-Occitanie (the official air quality monitoring agency). We have not been able to establish a collaboration with ATMO-Occitanie. It may be explained by the fact that the BREATHE project was perceived by the CEO of ATMO-Occitanie as an expertise competition and a threat to their economic development. The academics quickly realized that ATMO-Occitanie did not have sufficient resources to develop PM metrology at a street level, even though these data are of real interest to the community. Indeed, the population wants to know the quality of the air they breathe in their living spaces. We observe the democratization of low-cost sensors, easy to deploy everywhere. Our research project BREATHE is at the core of this ecosystem of measurements and citizen counter-expertise. ATMO-Occitanie is also at the core of this issue as it is the official agency whose measurements are directly considered by urban governances. One of our hypothesis is that the institutionalization of ATMO-Occitanie has been one of the obstacles to the BREATHE project. The public institution (the metropolis and the city of Montpellier) had already contracted with ATMO-Occitanie, which could be the reason

of the failure to establish a collaboration agreement with the metropolis and the city of Montpellier. Thus, the metropolis representatives did not see the need to collaborate with another partner. This hypothesis highlights difficulties in the construction of local public action which claims a desire for citizen participation in the decision making process:

Regarding the involvement and motivation of stakeholders in the project, we noticed a clear change over the course of the project. Indeed, as soon as the president of the metropolis and mayor of Montpellier announced the closure of the street to through-traffic and thus met the expectations of the citizens, the involvement of the latter largely decreased. This could be explained by the fact that the primary expectation of citizens was the closure of the street rather than gaining information on air quality. We have also questioned the limited effectiveness of public action on air pollution control. This could be explained by the fact that political authority is articulated at two scale levels: the metropolis and the city with different political and administrative competences. The objects of our research, fine-particle outdoor air quality and participatory democracy, are dealt separately by the metropolis and the city and are therefore subject to different political arbitrations. For example, the town hall representatives have taken the lead in developing their own form of participatory democracy to fulfill their democratic renewal promises. The two metropolis vice-chairs for the environment and for research who closely followed the project agreed to co-author this article because the results are of interest to the elected officials in charge of air quality. However, the latter asked us to appear simply in support of the project and finally refused to coauthor this article because the descriptive dimension reported here could be interpreted as critical on a social and political level. Such an interdisciplinary approach is not easy to implement and takes time for the establishment of a common protocol answering the different research questions of researchers. In addition, the choice of the Participatory Action Research (PAR) approach requires time to set up a cohort of co-researchers with citizens and to create a real collaboration with institutions (the agreement issue). In BREATHE, it was the university researchers who sought out and suggested that citizens join the project and not the other way around, as can be seen in the literature on PAR. The issue of having an agreement signed by the local institution (Metropolis or city of Montpellier) was important in our project. This would have made it possible to clarify the interests of the various stakeholders and would have ensured the neutrality of the researchers because the posture and expectations of each stakeholder would have been indicated in the partnership agreement. This allows to provide comfort for academics in a conflictual work environment. Two elements explaining the limit of collaboration could be investigated in

further research. The first one, surely comes from the fact that academics have decided at the beginning of the project to support the citizens while trying to get at first a collaboration with the Montpellier Metropolis. The second element to be explored later (this will also be the work of the doctoral student in political science) is the politicization of the air quality issue, which would explain the reluctance of elected officials to involve another actor in the management of this social and environmental issue. Only a continuation of this project research will permit to answer the hypothesis. At the time of drafting this paper, academics are still in discussion with elected officials and people working for the Montpellier metropolis.

The analytical contributions are relevant because they allowed to precisely describe the construction of public action on air quality at a local and a metropolitan scale. In this case study, the results demonstrated that consultation device developed by the metropolis of Montpellier is in tension between the Habermas-Mouffe conceptualization of public debate. More generally, this type of “democratic experimentation”, which aims at empowering citizens, does not fully redistribute the power of decision and action. Thus, the co-construction effort developed by the academics from the beginning of the project did not completely integrate citizen, metropolis representatives, and their project managers into the research program itself. The participatory research aspect remains limited. The work carried out by all the actors made possible to be at the center of the complexity of the tensions and attempts at power asymmetries. It invites to open a wider field interdisciplinary research program to cross-examine science in and for the society.

Conclusion:

- 1) A real and exploratory case study carried out inside a Montpellier (France) street canyon following a citizen science approach is presented. Focused on air quality monitoring, it allows a deployment of 60 passive filters and 12 *Hedera Helix* pot plants with a close contribution of citizen partners, already mobilized against the street through-traffic and its adverse environmental effect on air quality.
- 2) By means of the magnetic monitoring technique, this kind of citizen science survey is promoted. The benefits of the approach highlight a high-resolution data at the micro-scale, e.g., street level, where the formal air quality measurements from state-approved agencies are often few at the city-scale necessitating modeling to obtain the spatial variations at the scale of the district. The air quality magnetic monitoring method could

be perceived both as an alternative but also as a complement to help conventional monitoring.

- 3) A magnetic air quality index is proposed to standardize the magnetic monitoring of air quality. This index would attempt to democratize the magnetic data and facilitate the dialogue between all the stakeholders.
- 4) From a social and political points of view, a whole set of limits are detailed and, deserve to be pursued in view of its heuristic possibilities. Although, many questions remain to be addressed and overcome. This study remains at an exploratory stage. It deserves to be investigated in more depth by replicating it on several other districts. A major outcome highlights the need to deal analytically with the research project posture to supply future research work. At this stage, it seems appropriate to reproduce the study to assess the effectiveness of public action once the project to redesign the street with no traffic will be completed.

Author Contributions: Conceptualization, S.L., LSdA; environmental magnetism methodology, S.L; Citizen Science and Participative Action Research approach, LSdA, DDP; analytical experiments, S.L., P.N., C.P.; Deposimeters deployment, S.L., P.N., LSdA., C.P.; Magnetic equipment maintenance, P.N.; Citizen participation representative, C.P; Writing-original draft preparation, S.L., LSdA, and P.C.; Role of facilitator between elected officials, metropolis technical services, and study participants, R.P; Principal Investigator of BREATHE project, P.C.; All authors have read and agreed to the published version of the manuscript.

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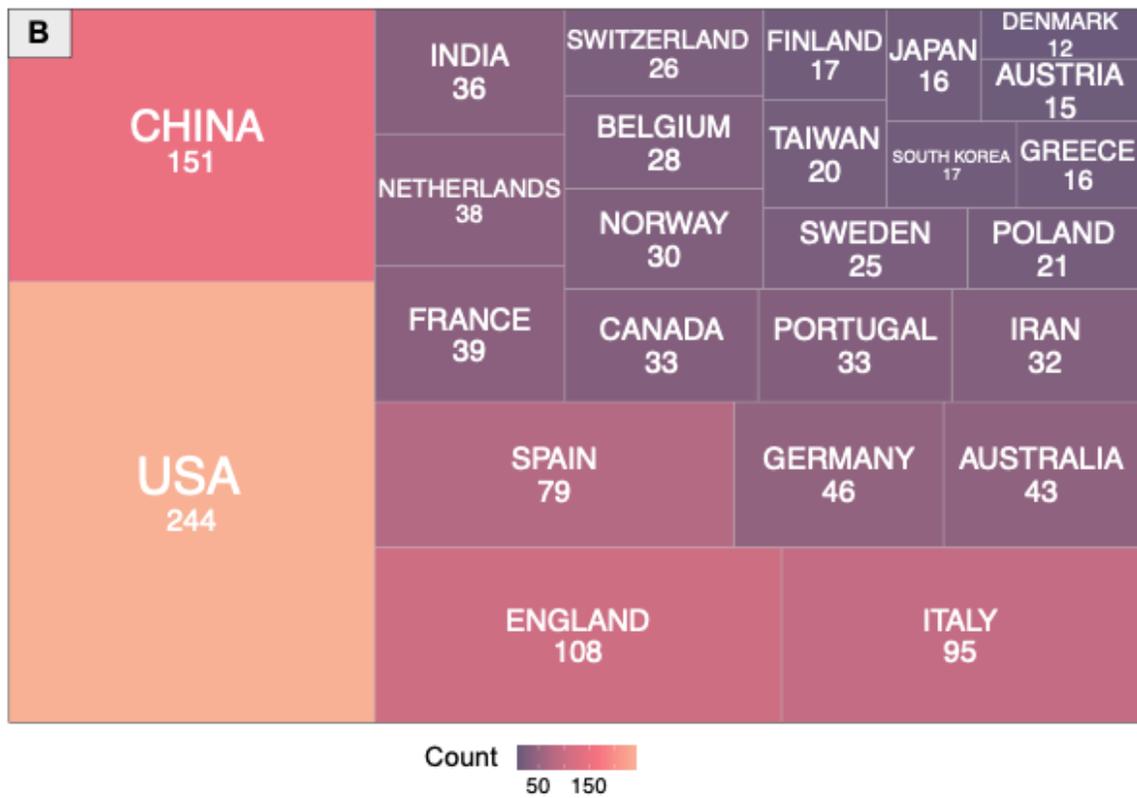
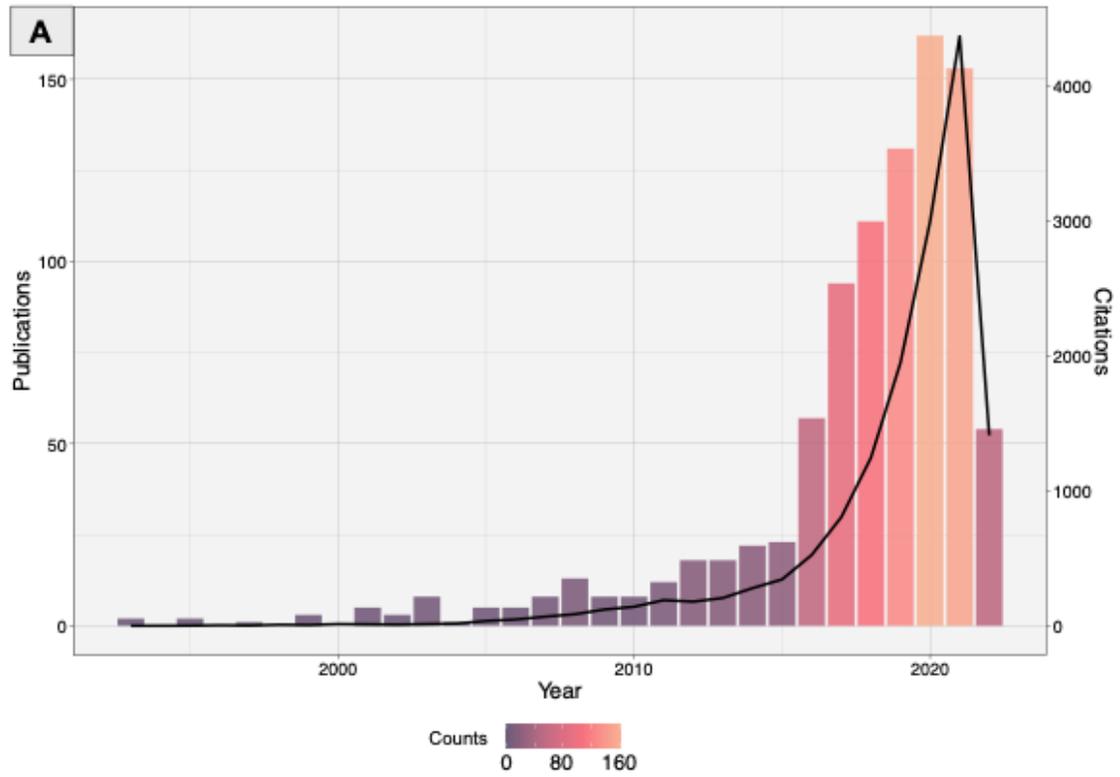
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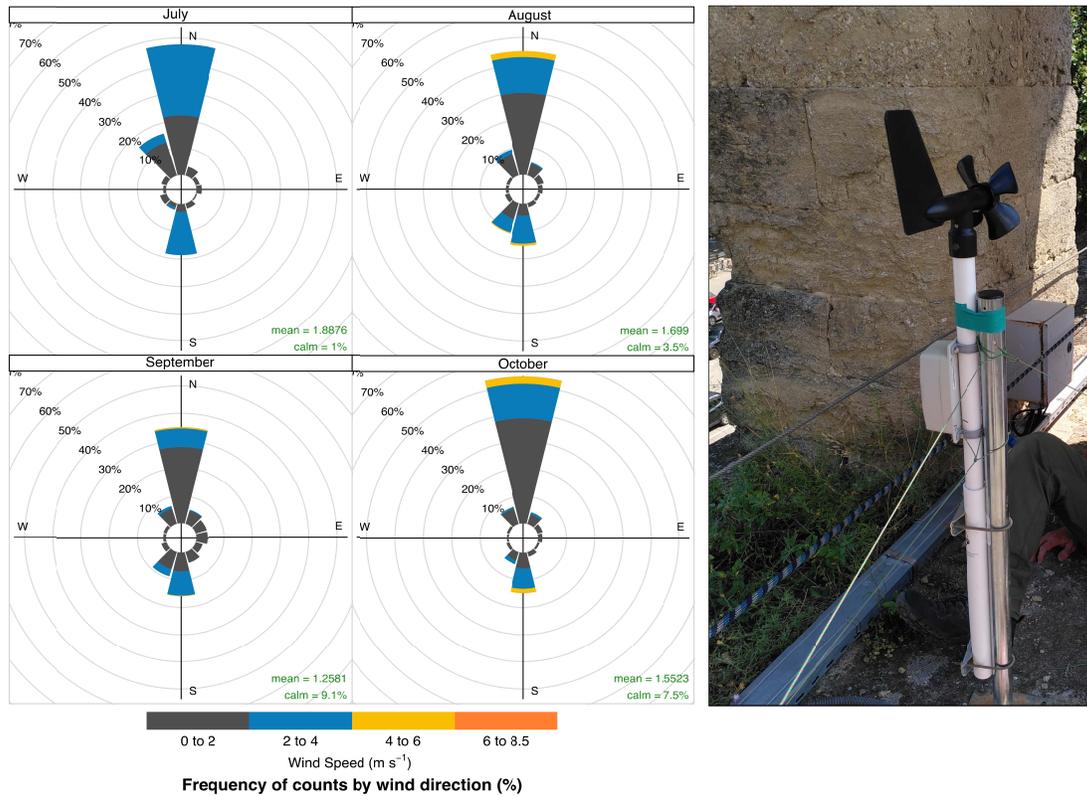
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Annexes

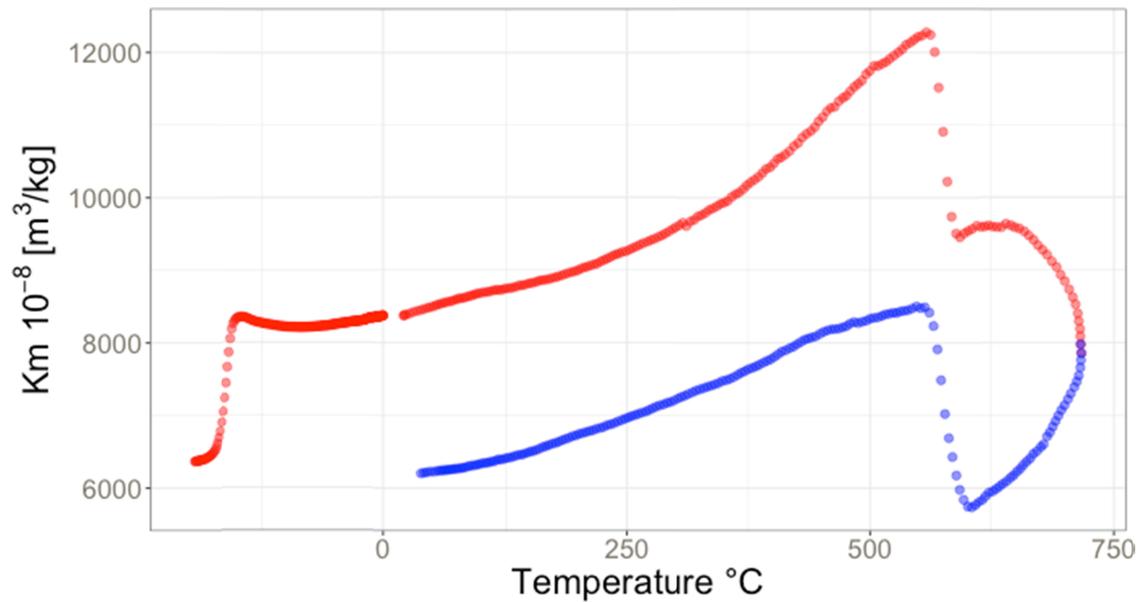


30 **Figure S1.** Bibliometric analysis performed from the "Web of Science core collection" database
 31 accessed on May 20, 2022 with the search query ((ALL=(Air quality) OR ALL=(Air pollution))) AND
 32 ALL=(citizen science). This search identifies 928 publications that are cited 12672 times. These
 33 results are illustrated with **(A)** a histogram of the number of publications (colored bars) and the
 34 number of citations (black solid line) per year since 1993 and **(B)** a "Treemap chart" where the
 35 areas on this chart are proportional to the number of publications per country as entered in the
 36 address field within the records. We have limited this graph to the 25 most represented
 37 countries

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 38 **Figure S2.** Wind roses for July, August, September, and October 2021, illustrating the
 39 prevailing wind speed and direction in the Saint-Louis canyon street that is oriented North-
 40 South (see Figure 1 in the main text).



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43 **Figure S3.** Magnetic susceptibility vs Temperature curves for brake pads illustrate the
 44 Hopkinson pick until 550°C and an inflexion around 600°C, suggesting the formation single
 45 domain magnetite. Also, we can see that another Curie point is not reached at 715°C, which
 46 would mean the presence of steel, pure iron or ferrite as well.

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49 **Table S1.** Air quality index developed by the national air agency of France. A qualifier (good,
 50 medium, etc) is assigned for each pollutant, according to its concentration in $\mu\text{g}/\text{m}^3$. The last
 51 line of the table presents a magnetic air quality index assigned for PM relative concentrations
 52 and measured by the IRM relative changes (dimensionless).

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		Good	Medium	Low	Bad	Very Bad	Extremely Bad
Daily average	PM _{2.5}	0-10	11-20	21-25	26-50	51-75	> 76
Daily average	PM ₁₀	0-20	21- 40	41-50	51-100	101-150	> 151
Maximum hourly per day	NO ₂	0-40	41- 90	91-120	121-230	231-340	> 341
Maximum hourly per day	O ₃	0-50	51-100	101-130	131-240	241-380	> 381
Maximum hourly per day	SO ₂	0-100	101-200	201-350	351-500	501-750	> 751
IRM relative change	PM	< 0-1	1-5	5-8	8-20	20-50	> 50

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Table S2. Data set of magnetic measurements for filters.

Samples	Floors	Charact	IRM100	IRM1000	Pseudo-S-ratio
B-002	2	80 mm filters	2,27E-04	2,77E-04	0,820143885
B-003	1	80 mm filters	2,29E-05	3,74E-05	0,611288605
B-004	3	80 mm filters	8,24E-05	1,11E-04	0,744328412
B-005	1	80 mm filters	2,04E-05	3,25E-05	0,626454378
B-007	2	80 mm filters	4,58E-05	5,49E-05	0,833212473
B-008	2	80 mm filters	1,01E-04	1,42E-04	0,711686494
B-009	1	80 mm filters	1,22E-04	1,62E-04	0,750859107
B-010	1	80 mm filters	5,54E-04	6,98E-04	0,79446189
B-011	1	80 mm filters	4,17E-05	5,74E-05	0,72528616
B-012	2	80 mm filters	4,87E-05	6,15E-05	0,792544571
B-013	1	80 mm filters	3,09E-04	3,75E-04	0,824654623
B-014	1	80 mm filters	8,05E-06	1,10E-05	0,734096692
B-015	2	80 mm filters	2,10E-04	2,77E-04	0,755922469
B-016	3	80 mm filters	1,89E-05	2,35E-05	0,805258694
B-017	1	80 mm filters	9,39E-05	1,26E-04	0,746594869
B-018	2	80 mm filters	2,12E-04	2,57E-04	0,821981424
B-019	1	80 mm filters	2,23E-05	2,75E-05	0,811320755
B-020	1	80 mm filters	1,87E-04	2,25E-04	0,828028294
B-021	2	80 mm filters	5,60E-05	7,49E-05	0,747273211
B-022	1	80 mm filters	2,20E-05	3,03E-05	0,72452334
B-023	2	80 mm filters	4,46E-05	5,57E-05	0,799857041
B-024	2	80 mm filters	8,22E-05	1,10E-04	0,749455338
B-025	1	80 mm filters	8,06E-05	1,10E-04	0,731081813
B-026	4	80 mm filters	6,21E-05	8,84E-05	0,702434626
B-027	1	80 mm filters	4,28E-04	5,44E-04	0,787545788
B-028	1	80 mm filters	3,91E-04	5,28E-04	0,739819005
B-029	2	80 mm filters	2,43E-04	2,87E-04	0,847434119
B-030	2	80 mm filters	2,83E-04	3,25E-04	0,871244635
B-031	2	80 mm filters	1,37E-04	1,99E-04	0,688744372
B-032	3	80 mm filters	6,27E-05	8,76E-05	0,715909091
B-033	2	80 mm filters	6,99E-05	8,87E-05	0,788811503
B-034	2	80 mm filters	1,24E-04	1,55E-04	0,801903782
B-035	1	80 mm filters	3,78E-05	4,79E-05	0,788117989
B-036	1	80 mm filters	8,18E-05	1,06E-04	0,770848986
B-037	2	80 mm filters	3,42E-05	4,44E-05	0,771095153
B-040	2	80 mm filters	9,03E-05	1,14E-04	0,792030758
B-043	4	80 mm filters	3,47E-05	4,90E-05	0,707317073
B-044	2	80 mm filters	9,51E-05	1,27E-04	0,751376869
B-045	1	80 mm filters	1,18E-04	1,63E-04	0,722086787
B-046	1	80 mm filters	3,56E-05	4,34E-05	0,820477502
B-049	3	80 mm filters	5,44E-05	7,27E-05	0,74828814
B-052	2	80 mm filters	7,29E-05	8,84E-05	0,824245155
B-053	1	80 mm filters			
B-054	1	80 mm filters	2,60E-05	3,36E-05	0,774748074
B-055	3	80 mm filters	5,02E-05	6,57E-05	0,763636364
B-056	1	80 mm filters-Ref station	3,84263E-05	4,68E-05	0,821200511
B-057	1	80 mm filters-Ref station	1,53406E-05	1,95E-05	0,787423313
B-058	1	80 mm filters-Ref station	2,07371E-05	2,61E-05	0,794656489
B-059	1	80 mm filters	1,31454E-05	1,68E-05	0,782799526

Table S3. Data set of magnetic measurements for *Hedera Helix* leaves.

Samples	Floors	Charact	IRM100	IRM1000	Pseudo-S-ratio
L-1-1	4	Plant	8,17E-05	9,29E-05	0,879738562
L-1-2	4	Plant	9,86E-05	1,46E-04	0,673581101
L-1-3	4	Plant	9,76E-05	1,16E-04	0,840222085
L-1-4	4	Plant	8,40E-05	1,16E-04	0,726253186
L-101	3	Plant	3,32E-04	3,96E-04	0,837719298
L-102	3	Plant	3,06E-04	3,79E-04	0,805600649
L-103	3	Plant	2,86E-04	3,64E-04	0,786576169
L-104	3	Plant	2,74E-04	3,37E-04	0,812339332
L-121	2	Plant	5,20E-04	7,24E-04	0,717888101
L-122	2	Plant	1,11E-03	1,52E-03	0,73168398
L-123	2	Plant	5,46E-04	7,49E-04	0,729266448
L-124	2	Plant	5,22E-04	7,28E-04	0,716955421
L-131	2	Plant	9,44E-04	1,31E-03	0,720207254
L-132	2	Plant	1,14E-03	1,57E-03	0,727630838
L-133	2	Plant	1,27E-03	1,76E-03	0,719129555
L-134	2	Plant	6,02E-04	8,32E-04	0,723913043
L-141	2	Plant	1,85E-04	2,42E-04	0,763670257
L-142	2	Plant	3,57E-04	4,73E-04	0,754926108
L-143	2	Plant	1,98E-04	2,66E-04	0,742182514
L-144	2	Plant	2,37E-04	3,20E-04	0,739069111
L-161	3	Plant	1,61E-04	2,13E-04	0,756236222
L-162	3	Plant	1,62E-04	2,07E-04	0,780703189
L-163	3	Plant	1,37E-04	1,76E-04	0,778525712
L-164	3	Plant	2,01E-04	2,63E-04	0,765129683
L-171	1	Plant_ Ref station	8,44E-05	9,47E-05	0,891176471
L-172	1	Plant_ Ref station	9,17E-05	7,74E-05	1,184981685
L-173	1	Plant_ Ref station	5,24E-05	4,50E-05	1,163467132
L-174	1	Plant_ Ref station	7,76E-05	8,14E-05	0,952259475
L-191	1	Plant_ Ref station	8,42E-05	9,84E-05	0,855540449
L-192	1	Plant_ Ref station	1,12E-04	1,37E-04	0,816455696
L-193	1	Plant_ Ref station	1,16E-04	1,28E-04	0,901106501
L-194	1	Plant_ Ref station	6,81E-05	8,01E-05	0,849364791
L-4-1	4	Plant	1,15E-04	1,39E-04	0,83230198
L-4-2	4	Plant	7,69E-05	1,08E-04	0,709854015
L-4-3	4	Plant	1,23E-04	1,33E-04	0,921323201
L-4-4	4	Plant	9,20E-05	1,22E-04	0,752130419
L-5-1	2	Plant	2,17E-04	2,85E-04	0,763647271
L-5-2	2	Plant	1,51E-04	1,95E-04	0,775761504
L-5-3	2	Plant	1,85E-04	2,73E-04	0,67638009
L-5-4	2	Plant	2,20E-04	2,70E-04	0,816065192
L-6-1	1	Plant	3,06E-04	4,03E-04	0,760443764
L-6-2	1	Plant	2,46E-04	3,08E-04	0,800477897
L-6-3	1	Plant	1,22E-04	1,98E-04	0,616873065
L-6-4	1	Plant	2,52E-04	3,73E-04	0,676808654
L-7-1	1	Plant	2,86E-04	4,82E-04	0,593378169
L-7-2	1	Plant	3,12E-04	4,06E-04	0,769722814
L-7-3	1	Plant	3,06E-04	4,91E-04	0,623634558
L-7-4	1	Plant	3,42E-04	4,45E-04	0,769352
L-8-1	2	Plant	3,27E-04	4,43E-04	0,737583
L-8-2	2	Plant	3,20E-04	4,72E-04	0,678955
L-8-3	2	Plant	2,60E-04	3,32E-04	0,783343
L-8-4	2	Plant	4,08E-04	5,40E-04	0,754566
L-9-1	1	Plant	2,31E-04	3,03E-04	0,762948
L-9-2	1	Plant	2,58E-04	3,34E-04	0,773932
L-9-3	1	Plant	3,21E-04	4,08E-04	0,786760
L-9-4	1	Plant	4,30E-04	5,54E-04	0,775254

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Table S4. Data set of gradual time exposure magnetic measurements performed on filters.

Samples	Floors	Charact	IRM1000
B38	2	1 month exposure	2,0395E-05
B39	2	2 months exposure	8,4781E-05
B40	2	3 months exposure	0,00011398
B41	4	1 month exposure	6,5889E-06
B42	4	2 months exposure	3,4343E-05
B43	4	3 months exposure	4,9004E-05
B47	3	1 month exposure	1,2559E-05
B48	3	2 months exposure	6,7968E-05
B49	3	3 months exposure	7,2729E-05
B50	2	1 month exposure	5,1245E-05
B51	2	2 months exposure	0,00011068
B52	2	3 months exposure	8,8406E-05

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Table S5. Bulk data of citizen partner feedbacks on the project.

Questions	Citizen partner 1	Citizen partner 2	Citizen partner 3	Citizen partner 4	Citizen partner 5	Academic 1	Academic 2	Academic 3	Academic 4
Expectations	8	8	4,5	7	7	9	6	3	5,5
Interests	9,5	8	9	10	10	10	10	10	10
Commitment	7	3	5	10	7	10	8,5	3	10
Pleasure	8,5	7	9	10	9	7	10	10	10
Knowledge of measurements	8	0	8,5	10	8	7	10	0	4
Health knowledge	0	0	1	7	1	7	0	0	0
Decision knowledge	10	0	0	10	9	8	6,5	0	4
Means to act	10	5	4	10	6	3	3,5	10	4
3D workshop	5			9	5	3	2,5		
Collaboration with researchers	5		6	10	8	7			
Collaboration with elected officials	7	1	8	0	5	1		1	0
Collaboration with residents	9	4	9	9	9	5	1,5	0	4
Collaboration with users	1	2	9	3	5		0		
Metrology protocol	8,5	8	8	10	8	10			
Appropriation of results	9	5	8,5	10	8				
PAR protocol	9	8	8	9	9	10	10	10	3

103