D4.3 CITIZEN SCIENCE REPORT ON DRIVERS AND BARRIERS IDENTIFIED

Date of document

28/07/2025

DELIVERABLE VERSION:
D4.3, V.04

DISSEMINATION LEVEL:
PU

AUTHOR(S):
Dalila Antunes; Francisco Nobre; Pablo Decelis; Shiva Noori

DOCUMENT HISTORY

PROJECT ACRONYM	AEROSOLFD
Project Title	Fast track to cleaner, healthier urban Aerosols by market ready Solutions of retrofit Filtration Devices for tailpipe, brake systems and closed environment
Grant Agreement Nº	101056661
Project Coordinator	M+H
Project Duration	01/05/2022 – 31/08/2025 (40 Months)
Deliverable No.	D4.3 Citizen Science report on drivers and barriers identified by all related stakeholder and target groups, guidelines for communication and communication effectiveness
Diss. Level	Public (PU)
Deliverable Lead	INTEC
Status	Working
	Verified by other WPs/Partners
	x Final version
Due date	30/04/2025
Submission date	28/07/2025
Work Package	WP 4 - Sustainability Assessment
Work Package Lead	NFA
Contributing beneficiary(ies)	NFA, M+H, Steinbeis, IUTA, CSIC, LINK, CENEX, ZF, SDA, CARTIF, Vert, INTEC, AVA, Conerobus, Metro Lisbon, LPP
DoA	T4.2 - Stakeholders ethical, societal and economic and market barriers and drivers (INTEC, NFA): Implementation of new technology may experience barriers due to cost, market or service constraints, reservations, anxiety, concerns about safety aspects or change. On the other hand, drivers such as quality improvements, leadership in risk reduction can be motivating factors and increase the uptake and implementation of new technology. In this task, we will consult with stakeholders representing relevant workers organizations (mechanics and service personnel), the public (public commuters and

NGO's), station owners and operators (retrofit costumers), and authorities (regulatory, policy) to identify barriers and drivers for potential uptake of the retrofit solutions. For this purpose, interviews and/or workshops will be developed with at least 10 organizations' representatives (workers' organizations, NGOs, owners and operators and authorities), and a short fine dust risk perception survey targeting at least 60 people (including different sex and age representatives), on three different testing sites. For all data types, potential gaps in final framework assessment data, values may be estimated by models, analogue data, expert opinions or qualitative input

T5.1 - Awareness raising materials will be pre-tested in different countries and its efficacy will be assessed through short surveys (a total of 200 people are planned to be surveyed along the project.

DATE	VERSION	AUTHOR	COMMENT
13/03/2025	1	INTEC	First draft of deliverable
19/03/2025	2	SDA / NFA	Internal Quality Control
31/03/2025	3	INTEC	Final version
28/07/2025	4	Steinbeis	Final version considering request for revision from 10/07/2025

**Co-funded by
the European Union**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
Ayuntamento Valladolid	AVA
Grupo Barraqueiro	Barraqueiro
Conerobus SPA	CB
Metropolitano Lisboa	ML
Rodoviária de Lisboa	RL
Transport & Environment	T&E

PUBLISHABLE SUMMARY

AeroSolfd project considered multiple ways of citizens engagement along its life-cycle. Citizen engagement was promoted through scientific proven methodologies fitting different purposes to gather relevant information for project development and exploitation. All the activities enhanced awareness about the effect of fine particles in human health and enhanced the critical thinking of different groups of stakeholders concerning air quality and AeroSolfd solutions.

The project performed two rounds for **pre-testing communication images and messages**, through which was possible to identify preferred colours, messages and images for communicating with the public.

In a series of **interviews** with key stakeholders including municipalities, private transportation companies, experts, and NGOs, several important insights and concerns regarding the implementation of pollution reduction solutions were identified. In summary, stakeholders across various sectors highlighted the importance of addressing pollution concerns and provided valuable insights into the challenges, considerations, and potential solutions in implementing air pollution reduction technologies. Collaboration between stakeholders and supportive governmental policies will be crucial in effectively mitigating pollution and improving air quality for communities. Some highlights can be provided for different groups. *Municipalities* expressed a commitment to addressing pollution concerns but highlighted barriers such as maintenance issues and compatibility with existing solutions. *Bus companies* raised concerns about potential negative effects of solutions on vehicle performance and maintenance. Interest was shown in solutions like air purifiers for bus terminals whilst challenges such as compatibility with vehicle warranties and approvals where highlighted. Suggestions for alternatives included the use of fuel additives and conversion to electric powerplants. And *metro operators* emphasized practical considerations such as space limitations and aesthetic concerns in implementing air purifiers in metro stations. *Experts* emphasized the importance of legislative support and financial incentives to drive adoption of pollution reduction solutions. They also emphasized the need for understanding the maintenance requirements and risks associated with the solutions. Suggestions included extending low-emission zones, promoting collaboration between EU countries in acquiring and reutilizing buses, and ensuring cost-effectiveness and attractiveness of solutions. Finally *NGOs* have advocated for a comprehensive approach to combating pollution, emphasizing the need to establish air quality standards that align with WHO guidelines and to promote zero-emission mobility options. They propose that governmental institutions apply various pressures to encourage compliance, including offering subsidies for adopting cleaner technologies, implementing more strict city regulations, imposing higher taxes on non-retrofitted vehicles, and holding car manufacturers accountable for not meeting emission standards.

A **survey** allowed to identify as main direct determinants of people attitude towards AeroSolfd solutions the attitude towards improvement of air quality in municipalities, the attitude towards transport particles, risk perception and, in a smaller scale, trust in government. perceived municipal air quality plays an indirect effect over the attitude towards AeroSolfd solutions, through the mediating variables of attitude towards improvement of air quality, risk perception and attitudes towards transport particles.

Two workshops allowed communities to validate and improve a **tool for raising awareness about life cycle assessment**. This tool allows empowering individuals to make informed choices about the products they use; advocate for sustainable production practices; and actively participate in community-level initiatives that promote circularity and sustainability.

In summary, the participation of the public had a significant impact in the AeroSolfed project namely through inputs to improve communication messages; insights on market acceptance of solutions, main barriers and facilitators; and information on how to better reach different groups of stakeholders including lay people.

1. INTRODUCTION

AeroSolfd project considers different ways of citizens engagement along its life-cycle. It uses citizen engagement through scientific proven methodologies to gather relevant information for project development and exploitation.

This deliverable presents the engagement approaches and methodologies used for citizen engagement as well as the main results produced and the way they contributed for the project implementation.

1.1. PURPOSE OF THE DELIVERABLE

The aim of this deliverable is to present the work developed by AeroSolfd projects on stakeholders' engagement and identify the main conclusions that informed AeroSolfd development. Namely this project provides information on five actions targeted on stakeholders engagement, each of them presented in a different chapter of the actual report:

- AeroSolfd Communication Messages

AeroSolfd communication was informed by a set of orientations defined during the initial stage of the project. AeroSolfd communication messages were pretested and the results of the pre-test informed the images and messages used during the project.

- Stakeholders' perspectives on AeroSolfd solutions

A set of interviews with different types of stakeholders (transport operators, municipalities, NGOs, and experts) provided information of main facilitators and barriers for the future implementation of AeroSolfd solutions.

- Citizens' risk perceptions towards air quality

Citizens' risks perceptions and their attitudes towards AeroSolfd solutions and investments are critical to understand the social consciousness about air quality problems and social acceptance of AeroSolfd solutions. It provides information of potential facilitators and barriers to AeroSolfd solutions market penetration.

- Citizens' awareness on life cycle assessment

This section describes the engagement of citizens through a game which aims to raise awareness on the environmental life cycle assessment of products.

1.2. CONTRIBUTIONS OF PARTNERS

Despite the authors of the report, different partners contributed to the work being developed. Namely it is important to emphasise a) the availability of end-user partners (AVA, AUVASA, Metro Lisbon) to be provide their perspectives during interviews with stakeholders; b) the relevant work of Steinbeiss on preparing the communication images and messages to be pre-tested; c) the team work provided by all partners which contributed to the dissemination of the citizens' survey through their own networks; d) the active role of CENEX on developing a game on LCA and on preparing LCA workshops with citizens.

2. PRE-TEST OF COMMUNICATION MESSAGES

2.1. OBJECTIVES AND EXPECTED IMPACT

The work developed under this chapter mainly contributed to WP6. The goal was to develop communication messages which are effective on catching the public and enhance their awareness on air quality problems and the relevance of AeroSolfd solutions.

In order to achieve this goal a initial set of guidelines to

2.2. GUIDELINES FOR RAISING PUBLIC AWAREESS ON AIR QUALITY

The quality and need for good and proper communication concerning air pollution and air quality has been scrutinized throughout the years, illustrating a clear picture that something is not functioning as intended. The lack of awareness about this issue and the difficulty of creating communication mechanisms that lead to awareness and, in turn, action or social acknowledgment, are often recognized, suggesting that communication about air quality and air pollution needs to be enhanced and attend to specific parameters that can improve the chance of success in creating this awareness.

According to the 2019 Air Quality in Europe Report, conducted by the European Environment Agency (EEA), air pollution leads to approximately 400 000 premature deaths annually in Europe alone, making air pollution the most prominent environmental threat the continent faces. Additionally, the World Health Organization (WHO) points out that this number rises to about 7 million deaths worldwide and that 9 in 10 people inhale air that exceeds the WHO guideline limits for air quality every day, deepening the severity of the issue and revealing the urgency for awareness about this topic as well as good communication that adequately transposes information.

On this matter, communication, and its quality is essential if a change is needed (as it is when it comes to air pollution and quality) since it is its effectiveness that will eventually dictate an increase or reduction of awareness and consequently a behavioural change concerning the matter presented. Also, if done correctly, a well-structured and designed communication program to increase attention to a particular topic could represent a direct way of bringing new legislation to play since it would possess the capability of creating social pressure demanding the implementation of such legislation. Thus, political change and the creation of laws that have air pollution and quality as a background concern can be endorsed by delineating good risk communication practices.

Concerning these practices, the literature on the topic gives some advice about things to avoid when communicating information, enumerating some points that should help improve the effectiveness of the communication itself and, consequently, awareness. Some of these points are explained below.

THE TARGET GROUP OF THE MESSAGE NEEDS TO BE WELL DEFINED

In these cases, although all the population should be alerted, the main priority should be on people with health problems that suffer the most from air pollution and lack of air quality.

Additionally defining the target group the message provided and the information has the capability of being more relatable and engaging, improving the possibility of behavioural change and creation of awareness.

GUARANTEE FREE ACCESS TO INFORMATION AND PROPER COMMUNICATION CHANNELS

Information about the influence of the air quality and pollution on public health should be easily accessible to all members of the target group and this includes choosing adequate channels to communicate; Channels as traditional media, interviews with relevant scientific figures, or creating new mechanisms that could help spread knowledge in a fast and easy way like mobile applications or through social media.

SCIENTIFIC DATA SUPPORTING THE MESSAGE SHOULD BE COMPREHENSIVE

Complexity-wise the information present should have detailed explanations and descriptions of what it means. Also, it should avoid ambiguities, clarify the terms presented and what those represent, avoiding too many "technical terms"; The use of graphics, images, or other figures that can help illustrate the data by visual means should also be adopted since it will help comprehension. If these last mechanisms are used, they too should be well accompanied by explanations and detailed data that can help foster its comprehension.

COMMUNICATION PROGRAMS SHOULD BE CREATED CONSIDERING STAKEHOLDERS

Stakeholders can be unconvinced and suspicious about scientific evidence, since, in terms of validity, the direct experience will be the most trusted source of risk for them. Therefore, the message should be compatible with the target group's context, presenting the issue as "local" as possible, and needs to be personalized congruently, avoiding the creation of too many forced contradictions with the reality lived by the stakeholders and possible dissonance.

STAKEHOLDERS SHOULD BE INVOLVED

Stakeholders should have some sort of participation in the study of air pollution and quality. Discussion with and among these populations should be promoted. By giving this type of access and participation, awareness about the problem should increase, and with it the capacity for advocating about this issue, creating social pressure.

PRESENT THE IMPACT ON HEALTH

The communication program should be clear about the negative impact of poor air quality and high pollution on health, laying down the diseases associated with this issue. Awareness should be increased if the target group considers the diseases as being serious and severe. Although solutions and ways to monitor and avoid these extreme cases should also be provided.

THE BENEFITS AND WAYS OF AVOIDING THE NEED TO BE DELINEATED

Just as important as the negative effect on health, the positive effects of avoiding exposure and changing behaviour to diminish pollution should be part of the communication program. By describing the positive effects on health that low air pollution and high air quality can have, stakeholders may, if effectively aware, create social pressure and push a political change that would regulate and ensure those positive effects in the future.

SPECIFIC DATA ABOUT THE POLLUTANTS SHOULD BE PRESENTED WITHOUT INDIVIDUALISATION IN A POSITIVE SCENARIO AND SHOULD BE INDIVIDUALIZED IN A NEGATIVE ONE

The different pollution agents should be presented together, making pollution and quality the interaction and participation of all of them. Presenting each one individually can produce negative effects on engagement with the messages and, in turn, result in a lack of awareness about the issue. However, in negative cases, where pollution levels are high and quality ones are low, the responsible agents should be individualized, diminishing stress and other negative outcomes related to this scenario.

NUMERIC DATA SHOULD BE PRESENTED IN PERCENTAGES

To have an engaging communication program, the numeric data should be delivered in percentages. Numbers can be seen as lacking context or very negligible, while percentages normally produce more engagement and are seen as more relevant.

COMMUNICATING INFORMATION ABOUT FINE PARTICULATE MATTER WITH A DIAMETER < 2.5 MM (PM2.5) POLLUTION

Pollutant Matter with less than 2.5 microns in diameter (PM 2.5) represents the greatest threat when in it comes to pollutant agents. According to the EEA 2019, PM 2.5 were connected with 412 000 premature deaths and 4 223 000 Years of life lost (number of years expected to live vs the years that the person lived) in 2016 and this number keeps increasing.

When it comes to source, road transport is one of the principal ones, 11% of all emissions of PM10 and PM2.5 come from it. Ranging from exhaust emissions to tires, PM2.5 are emitted through all these actions.

As conveyed when pointed out the contribution to premature deaths, the harmful effects on health that PM2.5 can bring are vast, being the principal agent in terms of impact in this field. Extreme cases of exposure, for example, can lead to lung and heart complications as well as brain-related problems.

Due to the announced relevance of these particles in terms of pollution context, it is urgent the creation of a communication program that alerts and creates awareness about it.

Having this in mind, a communication program designed to create awareness and impel behavioural change related to this kind of pollutant should follow the crucial communicational lines previously announced, having special attention when defining the target group of the program, since the health impact that this agent can have can vary in terms of age groups. Nonetheless, all the remaining points must be considered if a successful and effective campaign is desired. Additionally, instructions on how to monitor and control exposure to this agent, including the benefits and the harm that can come from it, need to be provided.

EFFECTS OF PM2.5 ON HEALTH AND HOW TO COMMUNICATE IT

As said previously, this type of particle has an extremely negative impact on health, leading to aggravation of existing health issues and the creation of others. High levels of PM2.5 exposure are linked with complications such as lung dysfunction in children, lung cancer, cerebrovascular diseases, both in children and elder people, heart failure, asthma in children, and hypertension to name a few.

Since these particles are so small it may be also plausible that, since children possess an underdeveloped respiratory system, without all the necessary defences that an adult already has, they may be more susceptible to problems related to high levels of exposure to this agent.

However, just like the awareness of this pollutant in general, when it comes to health risks, the scenario is also not ideal. Additionally, health communication needs to be tailored and specific, since it normally treats matters that can produce stress and other adverse reactions. Thus, health communication regarding air pollution and quality must follow principles such as benefits that a behavioral change can produce, presentation of alternatives to the existing type of behaviour (that can be prejudicial), attention to the complexity and quantity of information presented (to not overwhelm the targets) and have a detailed and well-defined target group to boost the relatability of the message. Additionally, statements made throughout the program should be adjusted to the local and specific target group and presented in a quantitative format, with images and illustrations to help comprehension and engagement.

2.3. RESULTS

2.3.1 ROUND 1

DEMOGRAPHIC DATA

The demographic data of the participants reveal a diverse distribution in terms of gender, age, nationality, and education level. Regarding gender, there were 147 participants in total, with 69 identifying as male, 77 as female, and 1 as other. The age distribution was varied, with 11 participants under 25 years old, 28 participants aged between 26 and 35, 34 participants aged between 36 and 45, 41 participants aged between 46 and 55, and 34 participants over 55 years old.

In terms of nationality, the majority of participants were Portuguese, representing 127 individuals. Austria was the second most represented country with 5 participants, Italy by 3 participants, Germany by 2 participants, while other nationalities, Belgium, Spain, Mozambique, the Netherlands, Angola, Denmark, and other European countries were each represented by 1 participant. Regarding education level, the distribution showed that 6 participants had completed primary education, 6 had completed basic education, 35 had finished high school, 55 held a degree, 37 had a master's degree, 14 were PhD holders, and 2 reported other educational qualifications.

ANALYSIS OF VISUAL PREFERENCES

This study focused on analyzing participants' preferences regarding different images presented to them. Participants answered three identical questions – "Which of these images do you prefer?" – evaluating their preferences for specific messages and visual elements.

The first question analyzed images related to ultrafine particles, with three distinct messages: "Ultrafine particles are dangerous to our health," "Ultrafine particles are lethal," and "Ultrafine particles have a major impact on our health." The results showed that the message "Ultrafine particles are lethal" was the most preferred, with 56 votes, followed by "Ultrafine particles are dangerous to our health," with 54 votes. The message "Ultrafine particles have a major impact on our health" received only 18 preferences. These results suggest that participants respond more favorably to messages that emphasize the harmful impact on health. The images presented contained illustrations

of lungs in the center, surrounded by airborne particles, with a green-toned background. The message text was positioned at the top of the image, standing out due to its contrast with the background.
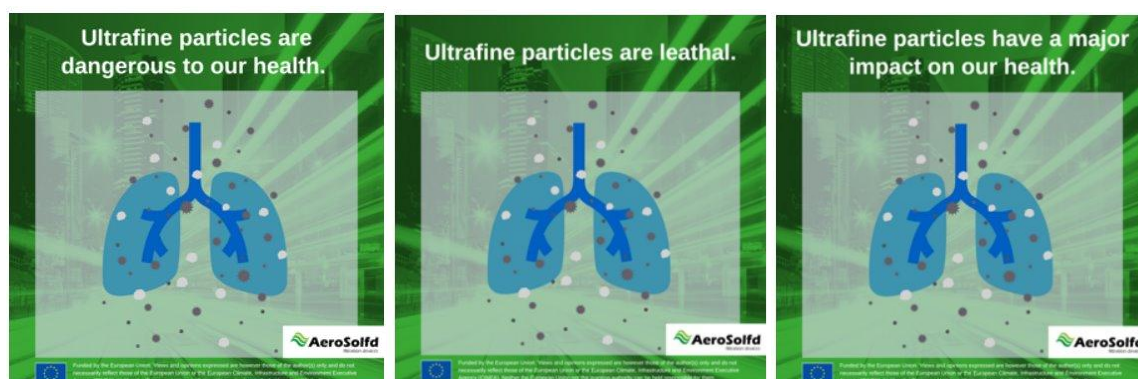
Figure 1 Which image do you prefer? (question 1)

The second question focused on participants' preferences regarding the shade of green used to convey the message "Health is Important," which was presented in three variations: light green, medium green, and dark green. The light green shade received 48 votes, while medium green garnered 47 votes, and dark green came in last, with 34 votes. The results indicate a stronger preference for lighter shades. The images in this category featured the phrase "Health is Important" prominently in the center, accompanied by an icon of a heartbeat and a heart, symbolizing health. The background was filled with varying shades of green – light, medium, and dark – with the visual elements centered to facilitate comparison.

Figure 2 Which image do you prefer? (question 2)

A variation of this analysis was conducted using the phrase "Health Matters," also displayed in light, medium, and dark green shades. In this case, light green was again the most preferred, with 45 votes, followed by dark green with 43 votes, and medium green with 40 votes. Although the differences were less pronounced, a general preference for lighter shades was confirmed. In this variation, the images displayed a stylized pair of lungs in the center, accompanied by the phrase "Health Matters" prominently, with a uniform green-toned background in each shade for comparison.
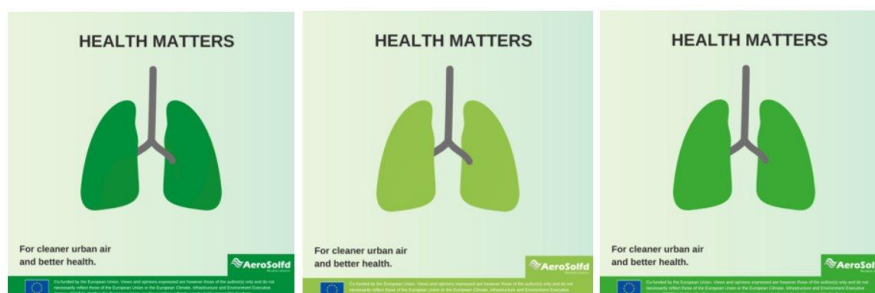
Figure 3 Which image do you prefer? (question 2)

Beyond colour, participants were asked about their preference between the formulations "Health is Important" and "Health Matters," comparing equivalent versions in light, medium, and dark green shades. In the light green category, the phrase "Health is Important" received 17 votes, while "Health Matters" was chosen by 23 participants. In the medium green category, the phrase "Health is Important" was chosen by 21 participants, while "Health Matters" received 17 votes. Finally, in the dark green category, the phrase "Health is Important" was preferred by 21 participants, while "Health Matters" was chosen by 18. These results indicate that, in darker shades (medium and dark green), the message "Health is Important" has slightly greater appeal, whereas in the light green shade, the preference shifts to "Health Matters" accompanied by the image of lungs.

Figure 4 Which image do you prefer? (question 3)

Figure 5 Which image do you prefer? (question 4)

Figure 6 Which image do you prefer? (question 5)

2.3.2 ROUND 2

ACTIVITY 1 – MESSAGING PREFERENCE

In the first set, respondents demonstrated a preference for Option 3, which received the highest selection rate at 35.6%. This was closely followed by Option 1, with 34.9%, and Option 2, which garnered 29.5%.

Figure 7 Which image do you prefer? (Messaging Set 1)
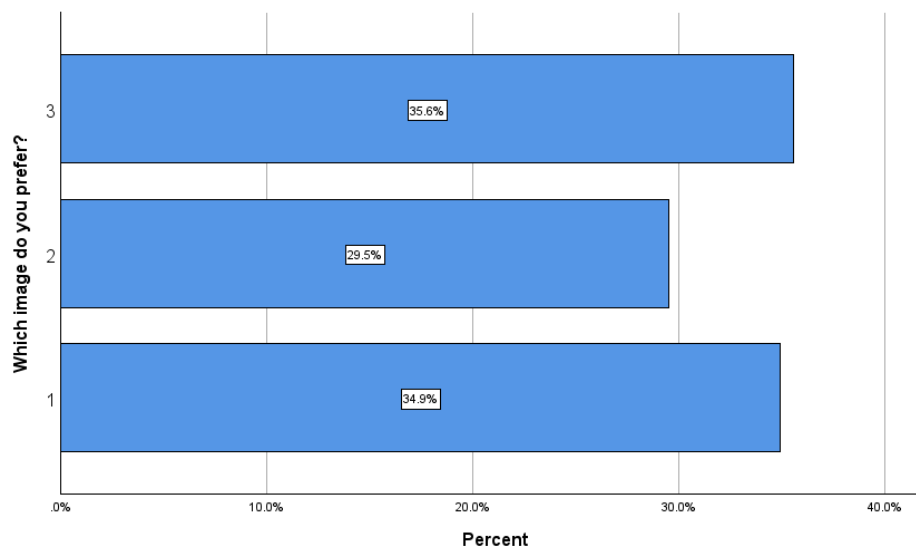
Figure 8 Distribution of results for messaging Set 1.

In the second set of messages, respondents once again showed a clear preference for Option 3, which achieved the highest selection rate at 36.5%. Options 1 and 2 exhibited nearly equal levels of preference, with 33.1% selecting Option 2 and 30.4% choosing Option 1.

Figure 9 Which image do you prefer? (Messaging Set 2)
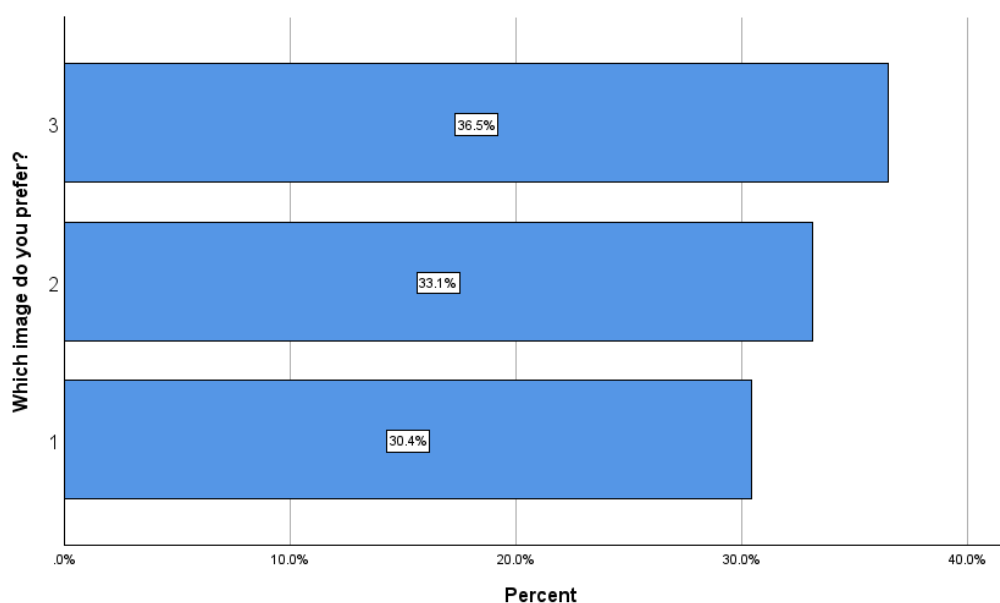
Figure 10 Distribution of results for messaging set 2.

In the third set of messages, respondents showed a clear preference for Option 2, which received the highest selection rate at 36.7%. This was followed by Option 3 with 32% and Option 1 with 31.3%.

Figure 11 Which image do you prefer? (Messaging Set 3)
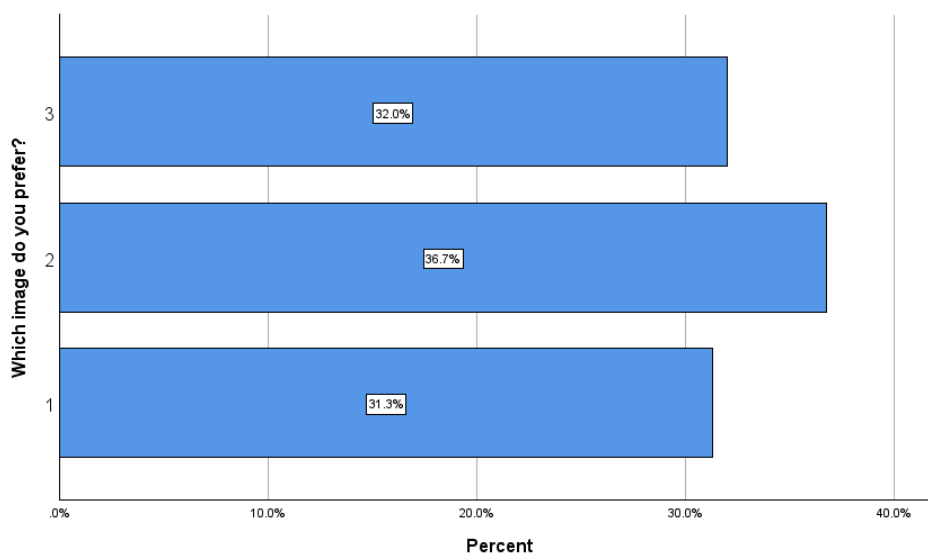
Figure 12 Distribution of results for messaging set 3.

In the fourth set of messages (Figure 7), preferences were nearly evenly divided, with Option 1 receiving a slight majority at 50.3% and Option 2 close behind at 49.7%.

Figure 13 Which image do you prefer? (Messaging Set 4)
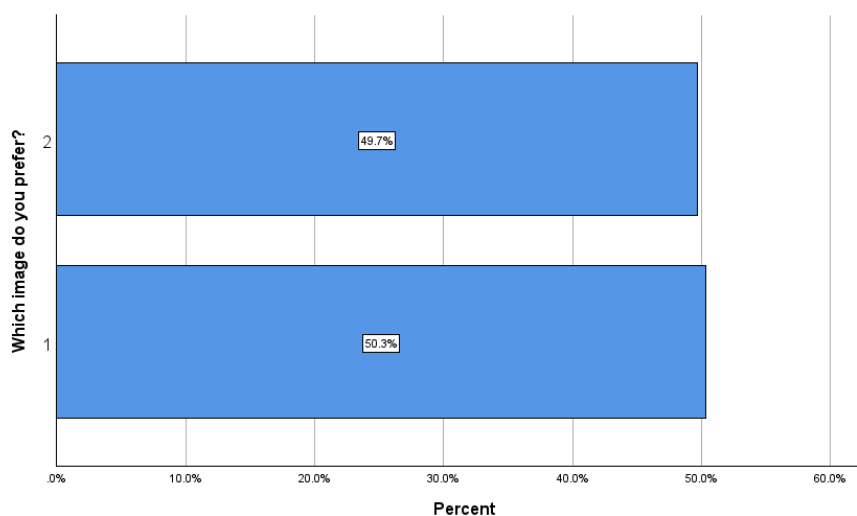
Figure 14 Distribution of results for messaging set 4.

In the fifth set, respondents demonstrated a strong preference for Option 3, which accounted for 39.5% of participant selections. This was followed by Option 2 with 30.6% and Option 1 with 29.9%.

Figure 15 Which image do you prefer? (Messaging Set 5)
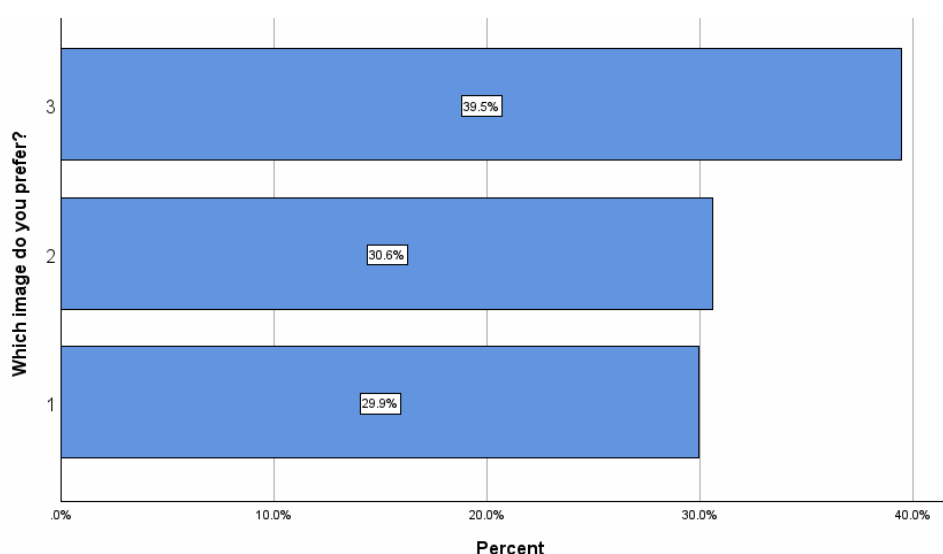
Figure 16 Distribution of results for messaging Set 5.

Lastly, in the sixth set, respondents exhibited a closely split preference between Options 1 and 2, with Option 1 showing a slightly higher selection rate at 35.8% compared to 34.1% for Option 2. Option 3 had a lower selection rate of 29.1%.

Figure 17 Which image do you prefer? (Messaging Set 6)
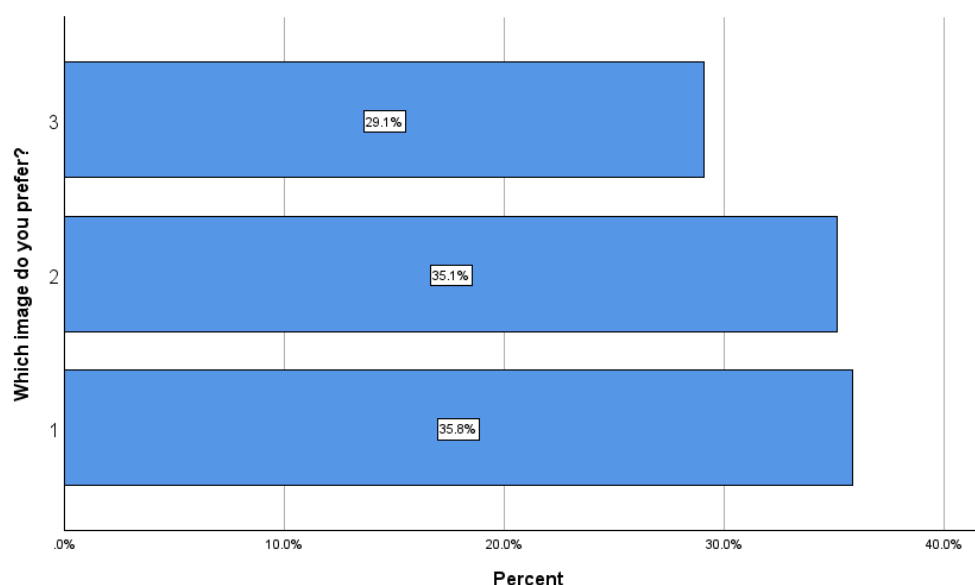
Figure 18 Distribution of results for messaging Set 6

2.4. CONCLUSIONS

The results highlight a preference for direct and impactful messages, such as "Ultrafine particles are lethal," and for lighter shades of green in health-related visual messages, emphasizing the importance of clarity and visual contrast. Subtle differences between phrases like "Health is Important" and "Health Matters" indicate that textual content also influences preferences, especially when combined with colour variations. Overall, participants' choices reinforce the importance of aligning visual and textual elements to effectively communicate public health issues.

3. STAKEHOLDERS' PERSPECTIVES ON AEROSOLFD SOLUTIONS

3.1. OBJECTIVES AND EXPECTED IMPACT

3.1.1. OBJECTIVES

The primary objectives of the interviews with different stakeholders are to analyse and leverage the insights gathered from interviews with key stakeholders and end-users. The specific aims are as follows:

- **Identify End-User Requirements**: Clearly define the needs and expectations of end-users to ensure the solutions meet their requirements.
- **Recognize Market Barriers**: Identify the barriers and challenges that make process of introduction and adoption of the solutions in the market more difficult. This includes understanding both technical and regulatory obstacles as well as social and behavioural resistance.
- **Determine Key Purchase Indicators**: Identify the indicators that influence purchasing decisions, ensuring the solutions align with market demands and are perceived as valuable by potential buyers.
- **Identify potential Indicators**: Exploit the indicators and feedback collected from the interviews to enhance the understanding of social, technical, and operational aspects of the proposed solutions.

3.1.2. EXPECTED IMPACT

The expected impact of this study is to provide comprehensive insights that will facilitate the successful market introduction and adoption of the solutions with minimal resistance or constraints. Therefore, taking in consideration end-user requirements and potential barriers, the report aims to:

- **Enhance Market Readiness**: Ensure that the solutions are fully prepared for market introduction by addressing potential issues beforehand.
- **Increase Solution Adoption**: Drive higher adoption rates by aligning the solutions with the specific needs and expectations of end-users.
- **Minimize Implementation Challenges**: Mitigate foreseeable challenges during implementation, ensuring smoother integration into existing operations and compliance with regulatory standards.
- **Improve Policy and Regulatory Alignment**: Create policies that support the integration of these solutions, thereby enhancing regulatory compliance and facilitate market acceptance.

Ultimately, the insights gathered through this research will provide a strong foundation for the solutions to be positioned effectively in the market, ensuring they meet the needs of all stakeholders and contribute positively to social and environmental outcomes.

3.2. METHODOLOGY

There was a total of 9 interviews with different stakeholders from several areas relevant to the project. The interviewed stakeholders are listed below, along with their respective category, the interview date and the person who was interviewed.

Table 1 – Interviews dates and interviewees

STAKEHOLDER	CATEGORY	DATE	CONDUCTED WITH
AVA – Ayuntamento Valladolid	Municipality/City	30/03/2023	Pedro Touya Mata
Grupo Barraqueiro	End-User (Bus)	03/04/2023	Rodrigo Taveira
Metropolitano Lisboa	End-User (Metro)	03/04/2023	Nuno Duarte
Conerobus SPA	End-User (Bus)	04/04/2023	Alessandro di Paolo and Paolo Rosetti
Rodoviária de Lisboa	End-User (Bus)	05/04/2023	João Rodrigues
Regional Health Administration of Lisbon and Tagus Valley	Regional Health Authority	05/07/2024	Vera Noronha, Lígia Ribeiro, Sónia Caeiro
Ute Bock	Expert	24/04/2023	Ute Bock
Transport & Environment	NGO	26/04/2023	Anna Krajinska
ZERO	NGO	27/04/2023	Francisco Ferreira

An interview script was developed with different options to match different types of stakeholders. Several entities were contacted to perform an interview. Those who agreed were approached using a semi-structured interview with questions tailored to their specific expertise and roles as end-users. The interviews were primarily used to capture feedback from end-users, focusing on how the solutions could be effectively accepted in the market and how policies could support their implementation. At the start of each interview, participants were asked for permission to record the session, so transcription was easier and more reliable; only one individual declined.

The interviews were analysed using a content analysis method. This approach enabled INTEC to systematically gather and evaluate critical information by allowing end-users to openly share their thoughts and experiences regarding the solutions presented. Content analysis allows for a thorough examination of the data following previously identified key themes in line with the goals of the interviews, providing insights into how end-users perceive and experience the solutions. This method ensures a comprehensive understanding of the end-users' perspectives, highlighting both their concerns and positive feedback on the proposed solutions.

During the interviews, the project's solutions were introduced to end-users through questions designed to uncover potential social issues and encourage a broad range of responses. The insights gained from these answers are vital for understanding the social impact of the project's solutions and

identifying the main concerns of current and prospective stakeholders. Moreover, this method provides a deeper understanding of the AeroSolfd solutions by highlighting the primary barriers faced by end-users, clarifying their requirements, and identifying new indicators to enhance the solutions' market exploitation and acceptance.

3.3. DESCRIPTION OF TECHNICAL/SCIENTIFIC ACTIVITIES

3.3.1. INTERVIEWS SCRIPT

The aim of the interviews was to find out more about the opinions of different stakeholders in relation to:

- ■ Giving more visibility to less visible issues such as health risks arising from air pollution.
- ■ Consult with stakeholders representing the public (public commuters and NGO's), station owners and operators (retrofit costumers) to identify barriers and drivers for potential uptake of the retrofit solutions.
- ■ Main concerns regarding the project.

The interviews were developed based on a semi-structured interview script which indicated the following as the main topics to be addressed for each type of stakeholder group.

NGOs

- What are you currently doing to combat PM2.5 particles?
- Do you know of any type of solution to combat PM2.5 particles?
- How do you evaluate these solutions?
- What would it take to tackle PM2.5 effectively?
- What do you think would be a good solution and how could we implement it?
- What pressures could be made at government level to implement these kinds of solutions?
- What do you consider important to partner on specific solutions? For example, to spread the to the public about a specific solution to combat PM2.5.

Solution Implementers

- Why did you join the *Aerosolfd* project?
- To what extent do you consider that the solutions envisaged by *Aerosolfd* are relevant solutions?
- What are the main obstacles to the implementation of these solutions?
- To what extent can the solutions provide answers to problems than can be considered important or not?
- Do you see yourself maintaining and implementing these solutions after the end of the project?
- What would you be willing to do to maintain and implement these kinds of solutions? What would be its limits or impeding factors?
- Do you know of any solutions to control PM2.5 particles?
- Have you tried to implement one?
- What would be a good solution for you?
- What factors would you need to gather to adopt these technologies?
- What do you think the solution technologies should have?

- How much are you willing to invest in these technologies?

Authorities/Municipalities

- How do you evaluate these solutions?
- What factors would you need to gather to adopt these technologies?
- What are the relevant criteria for evaluating these solutions (How do you evaluate the solutions – criteria and evaluation processes)?

3.3.2 SAMPLE

Initially, the following stakeholders were identified and contacted: AVA – Ayuntamento Valladolid; Auvasa; ConeroBus SPA; Grupo Barraqueiro; Lisbon City Council; Quercus Association; an expert in risk assessment; Rodoviária de Lisboa; Sofia Development Agency; Transport & Environment; ZERO Association; and the Regional Health Administration of Lisbon and Tagus Valley. Meetings were held with the representatives of these entities between the 30th of March and the 27th of April, with an additional interview conducted with the Regional Health Administration of Lisbon and Tagus Valley on the 5th of July 2024, as presented before on table 1.

3.4. MAIN RESULTS

The data was analysed using a content analysis approach. This method enabled INTEC to effectively collect and evaluate essential insights by allowing end-users to freely share their responses to the questions provided. The entities that agreed to participate in the interviews were engaged through a traditional interview format, which involved a series of questions specifically tailored to each end-user's area of expertise. This flexible approach in questioning allowed for a deeper understanding of the stakeholders' perspectives on the proposed solutions, capturing both their experiences and potential concerns

Solution Implementation

1. **WP3 Implementation**

   There is significant interest in adopting the air purifier retrofit solution as it is relevant and necessary for bus terminals. Bus depots are semi-enclosed environments where buses remain idling, leading to a higher concentration of PM2.5 particles and other pollutants.

■ **Conditions for Solution Implementation**

   The successful implementation of AeroSolfd solutions depends on several key factors, including client feedback, maintenance requirements, air quality indicators, filtration rates, and daily operations. It is also crucial to assess whether these solutions will enhance service quality and effectively reduce PM2.5 particle levels.

2. **Stakeholders Objectives**

   Stakeholders involved in the testing phase have specific objectives. Their participation is driven by the potential to identify the type and sources of PM particles, as provided by the project, as well as the effectiveness of the solutions themselves. There is also a clear intent to reduce

overall particle pollution, minimize the risk of lung diseases, and ensure the provision of high-quality transportation services to the community.

Main Barriers

1. **Maintenance interference**

   There were concerns regarding potential interference between the project's solutions and common vehicle maintenance. It was mentioned that new problems can arise by adding new solutions to vehicles.

2. **Third-Party implementations challenge**

   Resorting to third-party services for solution implementation may present difficulties, more specifically in public procurement processes. There is a perception that it may be easier if the service is managed by the city/municipality the solutions are being implemented in.

3. **Driver opposition**

   Opposition from vehicle drivers is possible if the projects solutions, more specifically WP1 and WP2, negatively impact vehicle performance or require big changes to normal maintenance routines.

4. **Regulatory and Certification Challenges**

   Some stakeholders' expressed concerns about the compatibility of the project's solutions with imposed requirements by the automotive certification authorities. Potential interferences with warranties and approvals of brand-new vehicles constitute a significant obstacle, making it necessary for authorization from vehicle manufacturers and governmental bodies.

5. **Bureaucratic Limitations:**

   Several problems and limitations were identified, such as more maintenance as a direct consequence of adding something new to the vehicles, like the project's solutions. Bureaucratic limitation such as manufactures warranties also presents a challenge, since that within the 7-year warranty that buses have, modifications can only be made with authorization of the manufacturer after the first 2 years of acquisition of the vehicles when they are brand-new.

◼ **Regulatory Challenges**:

   There are regulatory challenges and discrepancies between recommended values by the World Health Organization (WHO) and legal standards. The need for updates and alignment of legal standards with health recommendations is emphasized.

◼ **Awareness and Sensitization**:

   There is difficulty in raising awareness about the importance of PM 2.5 among relevant authorities and stakeholders, such as the CCDR (Regional Coordination and Development

Commission of Lisbon and Tagus Valley). Ensuring that these entities prioritize PM 2.5 as much as PM 10 is a challenge.

■ **Coordination Among Entities**:

Effective management and reduction of air pollution require coordinated efforts between national, regional, and local entities. The lack of coordinated strategies and measures between different levels of governance and entities is a barrier.

■ **Technical and Practical Challenges**:

The technical and practical challenges of adapting and implementing the filters for heavy vehicles and ensuring their effectiveness are noted. The need for ongoing testing and adjustments to the solutions is recognized.

■ **Public and Stakeholder Engagement**:

Involving local communities and stakeholders in understanding and mitigating air quality issues is seen as crucial. The need for strategies to effectively engage these groups and raise awareness about the project and its benefits is highlighted.

These barriers not only highlight the need for careful consideration of solution implementation strategies, and potential impact on vehicle operations, but also emphasizes the importance of addressing regulatory and bureaucratic challenges to ensure that the adoption and implementation of the projects' solutions are made in the most effective way possible.

Main Concerns

1. **Monetary Constraints**

    Affordability is a common concern among end-users, with cost constraints influencing the likelihood of solution approval. As such, solutions need to be economically feasible to align with stakeholders´ goals.

■ **Efficacy and Results**:

The interviewees express concern about the efficacy of the solutions and the availability of concrete results demonstrating their impact on air quality. The need for data and proof of success before making further evaluations is emphasized.

■ **Health Impact**:

There is a strong concern about the impact of PM 2.5 on health, including cardiovascular diseases, strokes, chronic obstructive pulmonary disease and lung cancer. The importance of reducing PM 2.5 levels to improve public health was highlighted.

■ **Implementation Feasibility**:

Questions are raised about the practical implementation of the solutions, including the ability to implement them effectively in different environments (urban, industrial, etc.).

■ **WP1 Concerns**

Implementation challenges related to WP1 were identified. There were concerns regarding the adoption of the tailpipe retrofit solution from the public as it implies that people spend additional money to have this technology fitted to their cars. Negative side effects from the tailpipe retrofit could also arise, such as decreased vehicle performance and increased fuel consumption if the tailpipe filter gets clogged, like problems seen with Diesel Particle Filters (DPFs).

■ **WP2 Concerns**

The main concern with WP2 Brake filter solution is related to vehicle safety. It is essential that vehicle braking isn't compromised by the filter, therefore putting passenger safety at risk.

■ **WP3 Implementation Challenges**

Long-term usage of air purifiers requires positive testing outcomes and cost compatibility with stakeholders´ budgets. Air purifier implementation in metro stations presents physical, functional and aesthetic challenges, including space limitations, safety concerns, and vandalism risks.

These challenges underline the importance of considering <u>affordability, safety, and functionality concerns</u> to ensure the successful implementation and adoption of AeroSolfd solutions.

Experts Suggestions and Concerns

1. **Financial Incentives**

Experts suggested offering filters at more attractive prices to increase awareness and encourage solution adoption. This approach aims to distance consumers from negative impacts of emissions and raise awareness about air quality issues. Also, understanding the key drivers of PM particle emissions is essential for effective control measures.

2. **Risk Assessment for Air Purifier Solutions**

To identify potential hazard risks with WP3, experts proposed asking critical questions:

- How much energy is necessary to operate the air purifier?
- Are the energy sources environmentally friendly?
- How much maintenance is necessary?
- Is it easy to install?

As such, understanding the maintenance requirements for the filters and potential risks associated with the solutions, such as risk of inflammation of air purifiers filters, is crucial for effective implementation.

3. **Regulatory Framework**

Regarding WP1, experts suggested that establishing a regulatory scheme mandating the adoption of tailpipe retrofit solutions, like the approach taken with DPFs, could facilitate the

adoption process. Such a scheme would provide a framework for enforcing compliance and incentivizing adoption.

4. **Collaborative Efforts in Public Transportation**

Experts mentioned the need for increased collaboration among European countries in acquiring and repurposing buses to enhance resource utilization and improve the sustainability of public transportation systems.

5. **Extension of Low-Emission Zones**

There is a consensus among experts on the importance of extending low-emission zones in urban areas to control the spread of particles and improve air quality.

6. **Control of Gases Forming PM2.5**

Experts stressed the necessity of controlling the gases that form PM2.5 particles to effectively manage air pollution.

7. **Relevance for Brake Manufacturers**

WP2 brake system retrofit solution must be relevant for brake manufacturing companies, potentially leading to the use of alternative materials to reduce brake emissions. Providing brake filters at more attractive prices could also incentivize adoption and raise awareness.

These recommendations will allow for stakeholders to address financial barriers, mitigate risks, and establish frameworks to facilitate the adoption and effectiveness of the project's solutions.

Alternatives

1. **District Heating with biomass and Chimney Filters**

Stakeholders mentioned the implementation of district heating with biomass and chimney filters to mitigate particle emissions, particularly in areas where air pollution is more concerning.

2. **Vehicle-Based Purification Systems**

Experimental vehicle-based purification systems are being developed and implemented, including rooftop filters on buses to capture PM2.5 and PM10 particles, as well as in-vehicle air purification systems applied to buses.

3. **Technological Innovations in Transportation**

Stakeholders have adopted fuel additives to improve combustion efficiency and reduce emissions, converted an internal combustion engine powered bus to electrical power, and installed solar panels on buses. New machinery for wheel grinding has been introduced to minimize particle generation during metro operations.

4. **Pollution Measurement in Ports**

There was mention of initiatives like pollution measurement equipment for cruise ships in ports, highlighting the importance of monitoring and regulating emissions in various sectors.

Proposed Additions to AeroSolfd Solutions

1. **Automated Monitoring Systems**

   Potential stakeholders interviewed suggested the development of an automated monitoring system to observe air quality changes, allowing for the observation of air quality evolution.

2. **Improved Portability of WP2 Retrofit Solution**

   It was also proposed making the retrofit brake solution more portable, allowing them to be applied to various types of vehicles, improving their versatility and applicability.

3. **Production Fragmentation and Localization**

   There is potential for fragmentation of the production of the solutions, with components like brake filters being produced in different regions to improve accessibility and affordability.

4. **WP1 Tailpipe Broader Vehicle Application**

   It was suggested that WP1 tailpipe retrofit solutions be extended to diesel vehicles without DPFs.

NGO initiatives

1. **PM2.5 Pollution Mitigation**

   The NGOs interviewed are engaged in various initiatives such as: aligning air quality standards with WHO guidelines, setting CO_2 standards for Heavy Duty Vehicles and Light Duty Vehicles, and advocating for emission reduction measures such as low and zero emission zones in line with Clean City Initiatives.

2. **Greener Mobility**

   It was emphasized the necessity to reduce private vehicle mileage and promoting public transportation accompanied by a transition to e-mobility. It is also necessary to advocate pollutant standards for non-exhaust emissions like those from tyres and brakes.

3. **Rail Transport Promotion**

   The NGOs are promoting policies to enhance rail transport competitiveness and reduce reliance on aviation. This could be relevant to promote WP2 Brake System Filters in rail transportation.

Pressures on Governmental Institutions

1. **Subsidies Offers**

   Offering subsidies to encourage retrofitting of the most polluting vehicles with tailpipe particle filters, such as the WP1 solution.

2. **City Regulations**

   Enacting city regulations requiring vehicles to be fitted with pollution-reduction technologies to enter certain zones.

3. **Higher Taxation**

   Implementing higher taxation for vehicles not retrofitted with technologies like DPFs and WP1 tailpipe filter solution.

4. **Financing**

   Requiring carmakers to pay for retrofit of vehicles which do not comply with the relevant pollutant emission standards on road e.g. Euro 5 vehicles not complying with the Euro 5 standard.

3.5. CONCLUSIONS AND RECOMMENDATIONS

The interviews provided valuable insights into the implementation challenges, stakeholder concerns, expert suggestions, alternative solutions, and governmental pressures regarding the adoption of AeroSolfd solutions for mitigating particle emissions in transportation and public spaces.

It is evident that while there is a clear interest in adopting solutions like air purifiers and tailpipe retrofit technologies to address air quality issues, several barriers exist that need to be carefully addressed to ensure successful implementation.

Therefore, the following recommendations should be considered:

- **Regulatory Framework Strengthening:** Talk with policy makers on how regulatory frameworks like those for Diesel Particle Filters (DPFs) can be applied. This can facilitate the adoption of tailpipe retrofit solutions (WP1) and incentivize compliance among vehicle owners and manufacturers.
- **Financial Incentives:** Offering financial incentives such as subsidies. This can encourage the retrofitting of vehicles without any particle filter. This approach is in line with governmental pressures and can significantly mitigate one of the main issues among end-users, the affordability of the solutions
- **Expansion of AeroSolfd solutions:** For future projects, the tailpipe retrofit can, for example, be extended to older diesel vehicles without DPFs
- **NGO Engagement:** NGOs experience can strengthen initiatives aimed at aligning air quality standards with international guidelines, promoting greener mobility, and advocating for emission reduction measures. Their involvement can raise public awareness and support for AeroSolfd objectives.

Follow-up Actions:

1. Initiate discussions with authorities and policymakers to enact or strengthen regulations mandating the adoption of pollution-reduction technologies in vehicles. In extension facilitating the application of WP1 Tailpipe retrofit solutions.

2. Foster collaboration among relevant stakeholders, including governmental institutions, NGOs, and industry players, to streamline solution implementation and address regulatory challenges collectively.

3. Establish mechanisms for continuous monitoring and evaluation of solution effectiveness, including the development of automated monitoring systems.

4. Explore opportunities for expanding the application of solutions and engaging with stakeholders to ensure alignment with evolving needs and priorities.

4. EVALUATION OF CITIZENS' RISK PERCEPTIONS TOWARDS AIR QUALITY

4.1. INTRODUCTION

The primary objectives of the interviews with different stakeholders are to analyse and leverage the insights gathered from interviews with key stakeholders and end-users. The specific aims are as follows:

4.2. ANALYSIS

PERCEIVED MUNICIPAL AIR QUALITY

As shown in Figure 13, approximately 63.4% of the sample rated the perceived municipal air quality above 5, indicating an overall positive evaluation (M = 4.71, SD = 1.22). No respondent rated the air quality as "Extremely Bad," while 4.5% rated it as "Excellent," demonstrating a stronger tendency toward positive assessments.
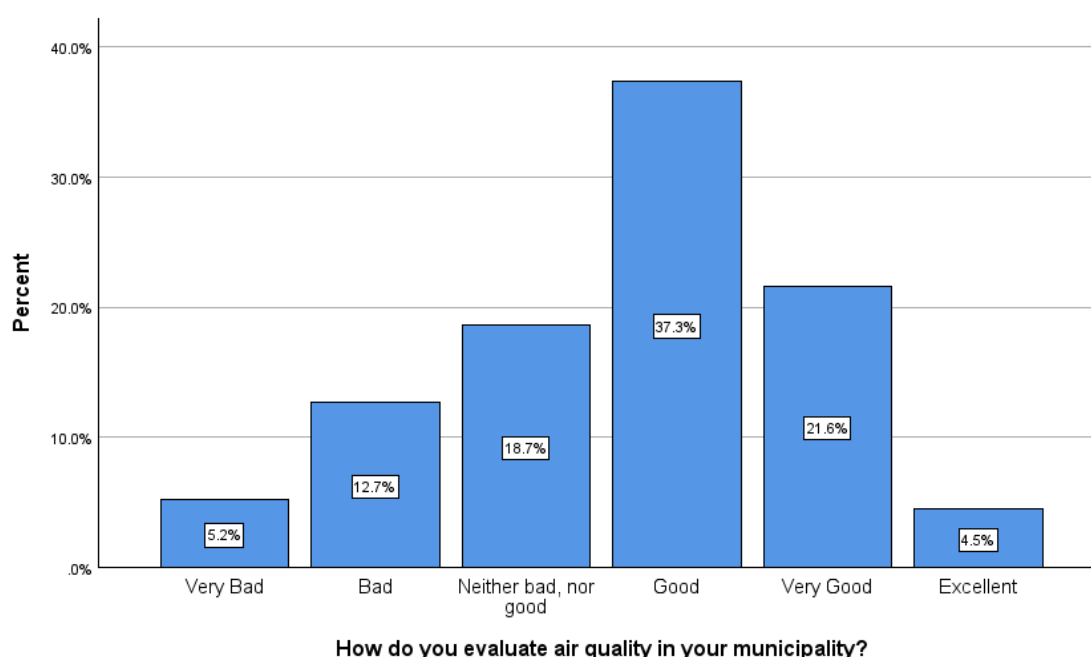

Figure 19 Results distribution in Perception of Municipal Air Quality scale

Regarding the comparative analysis between groups, t-tests and ANOVAs were conducted to examine differences based on gender, age, and education level. No significant results were found for gender, age nor education.

ATTITUDES TOWARDS TRANSPORT PARTICLES

Most participants (37.3%) identified transport particles as a "Big problem," with an additional 29.9% considering it a "Common problem." A combined 24.6% viewed it as a "Very big problem" or "Huge problem." Only 6.0% rated it as a "Small problem," and 1.5% considered it "Not at all" a problem. This indicates a general concern about transport-related particle emissions. The mean score was 4.86, with a standard deviation of 1.19, reflecting a moderate to high level of concern overall.
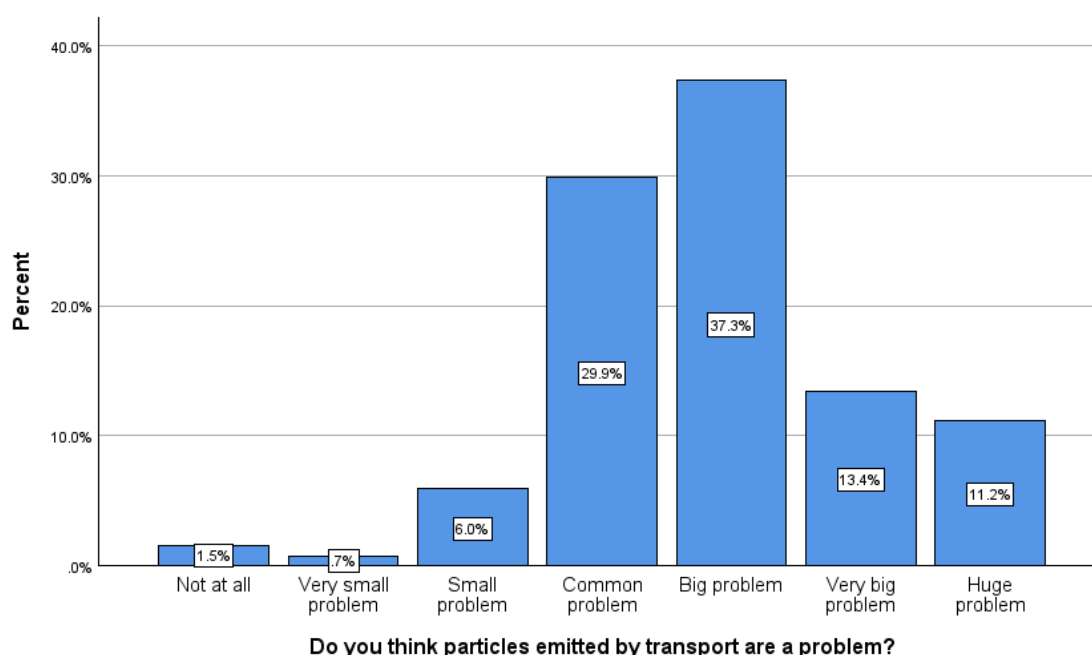

Figure 20 Results distribution in Attitudes towards transport particles scale

Regarding the comparative analysis between groups, t-tests and ANOVAs were conducted to examine differences based on gender, age, and education level. No significant results were found for gender, age nor education.

Significant differences were observed in relation to gender (d=1.2, t(128)=1.91, p=0,012), with women (M = 4.43; SD = 1.22) reporting a poorer evaluation of air quality in comparison to men (M = 4.84; SD = 1.19).

RISK PERCEPTION

This scale has a response mean of 4.66 (SD = 1.30), which is above average and quite close to the value (5) of the numerical scale, which represents "Negatively Affected". In other words, on average, the population holds a moderate to high-risk perception toward fine particles impact on individual and social health. Analyzing the graph, the most representative values lie between 4.29 and 6.0.
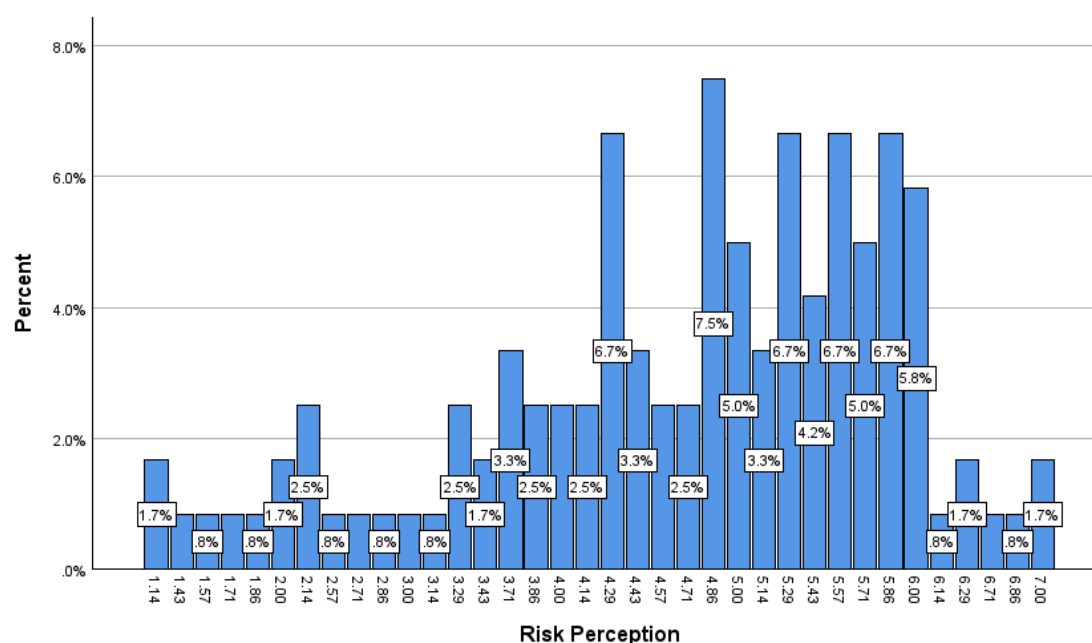
Figure 21 Results distribution in Risk Perception scale

The following is an individual analysis of the questions assessing risk perception, starting with the first three questions of the survey, related to the individual, family, and overall impact of fine particles on health. As observed, the evaluation of the overall impact, compared to more proximal evaluations (self and family), was rated more negatively, with most participants (75.3%) scoring above the mean. In contrast, individual evaluations accounted for 35%, and familial impact was rated at 36.6%.

This finding is not unexpected in psychological terms. People's mind tends to pursue a protective effect, avoiding raising stress levels and anxiety. Hence individuals tend to downplay the perceived risk or impact of an issue when it affects them personally or their close family members but view the broader, collective impact more negatively. This phenomenon suggests that people may perceive risks as less threatening when the consequences are closer to them and their loved ones, but more concerning when they consider the wider community or future generations.
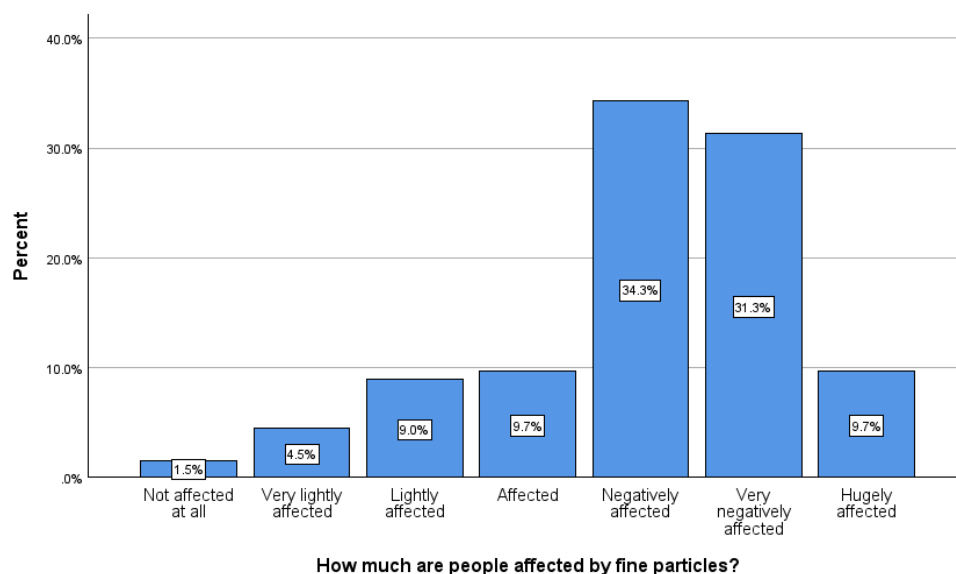
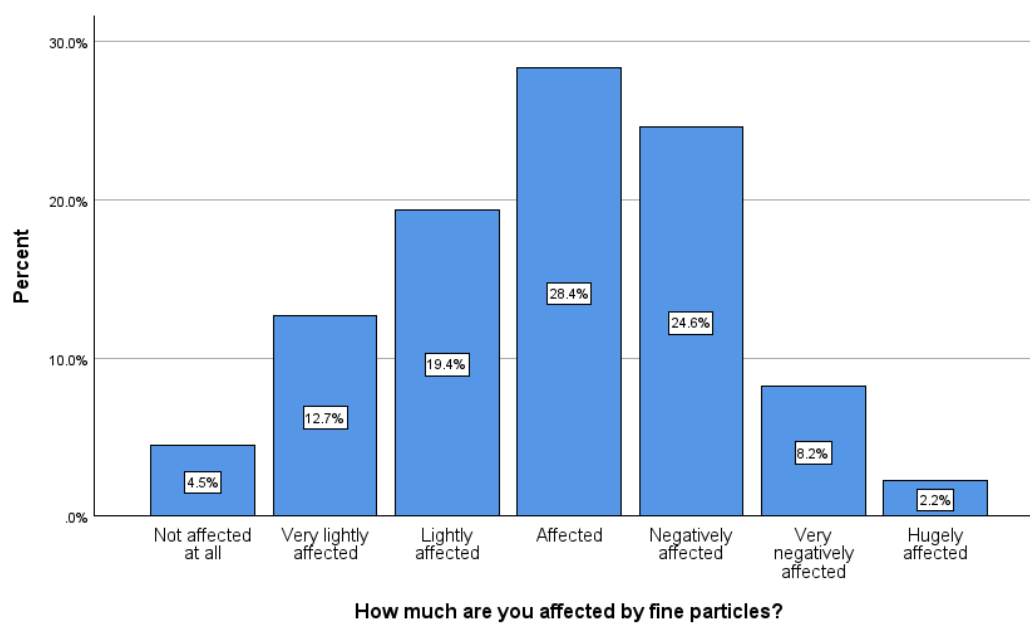*Figure 22 Responses to question How much are people affected by fine particles?*

Figure 23 Responses to question How much are you affected by fine particles?
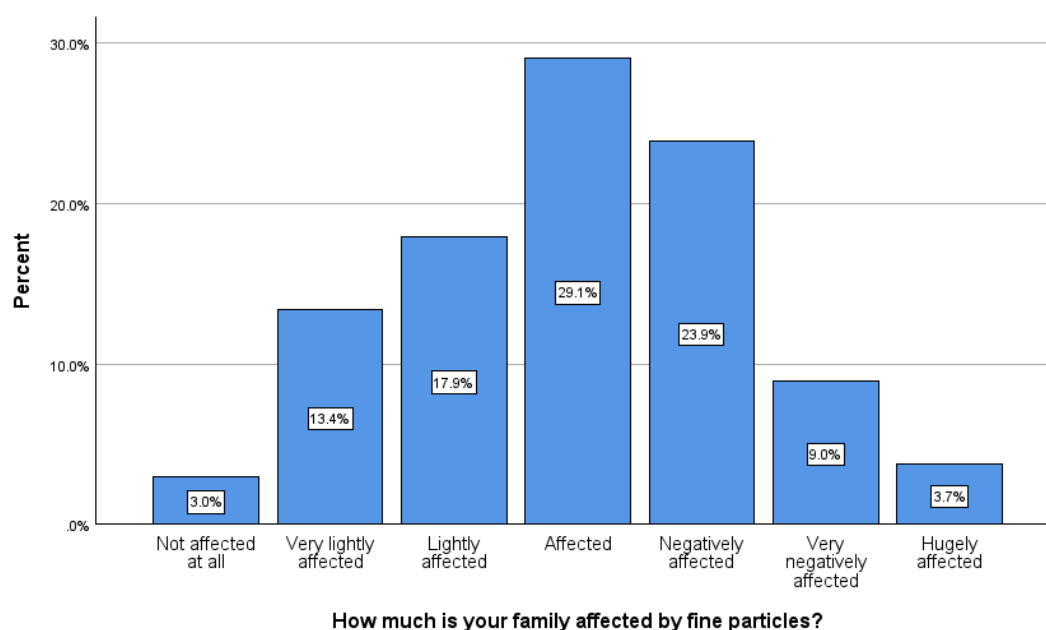
Figure 24 Responses to question How much is your family affected by fine particles?

Moving forward, we now focus on the impact of fine particles on specific organs in the human body. As expected, the organ perceived to be at the highest risk was the lungs, with 35.2% of respondents rating it at the highest scale point, in comparison to other percentages: heart (16.7%), blood (13.2%), and brain (10.7%).

Overall, individuals tended to rate the impact on these organs as negative or very negative, as indicated by the mean scores for each question: MLungs = 5.72, MHeart = 4.85, MBlood = 4.65, and MBrain = 4.48 (value 7 corresponds to hugely affected and value 1 corresponds to not affected at all). This suggests a general high concern regarding the detrimental effects of fine particles on health.

Figure 25 Responses to question How much do fine and ultrafine particles affect – The lungs

Figure 26 Responses to question How much do fine and ultrafine particles affect – The heart
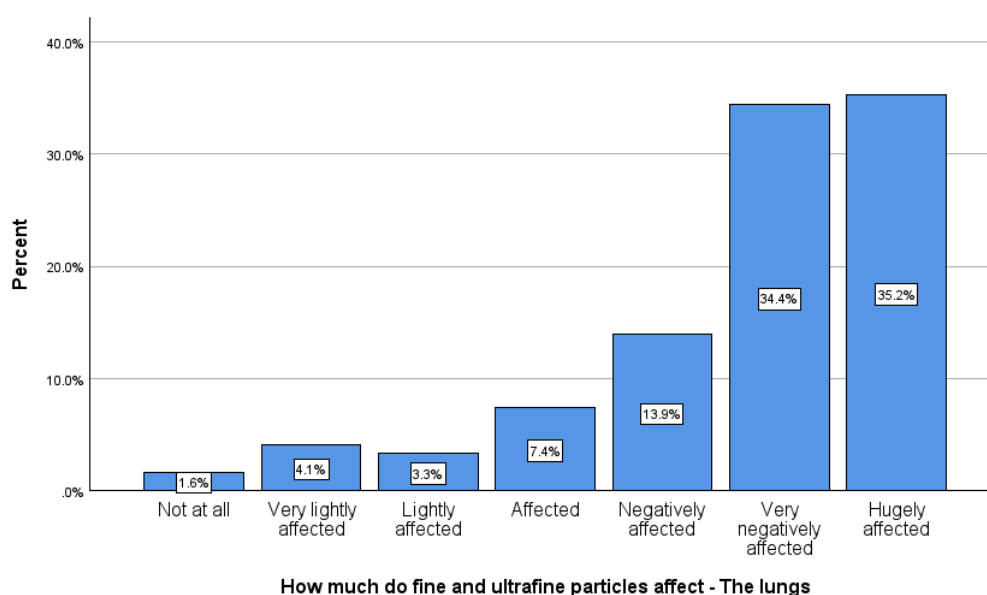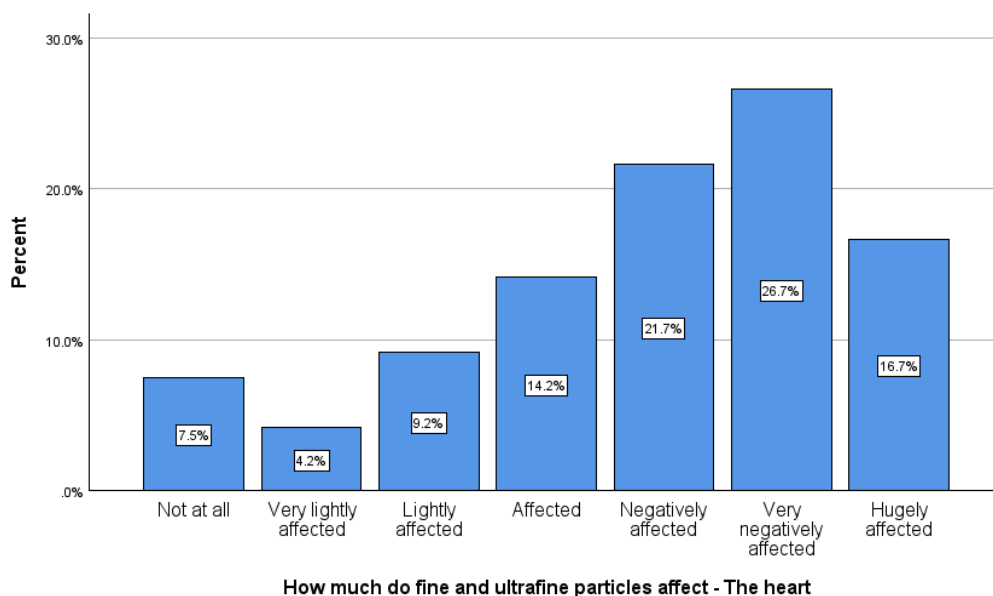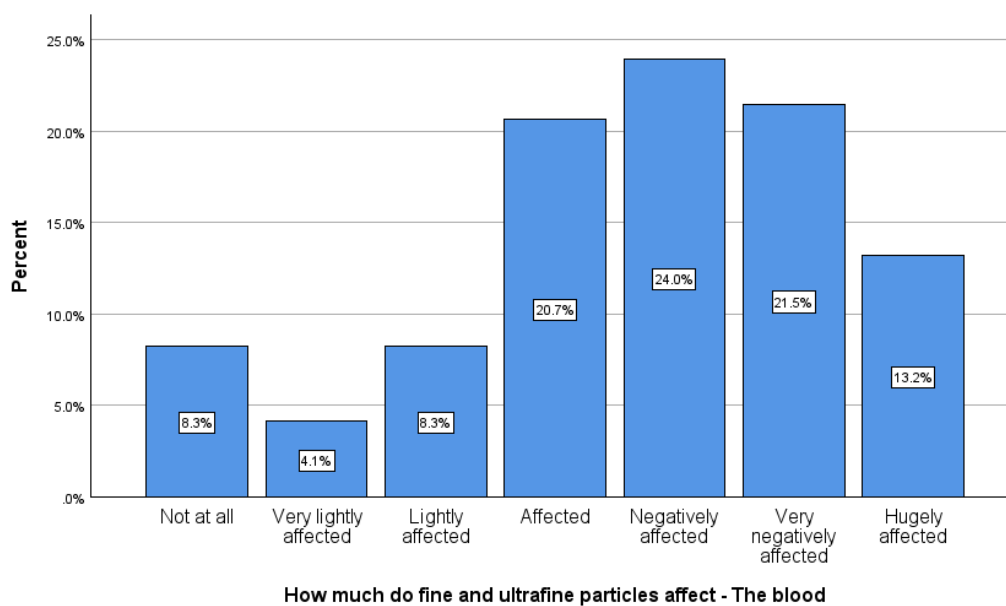

Figure 27 Responses to question How much do fine and ultrafine particles affect – The blood
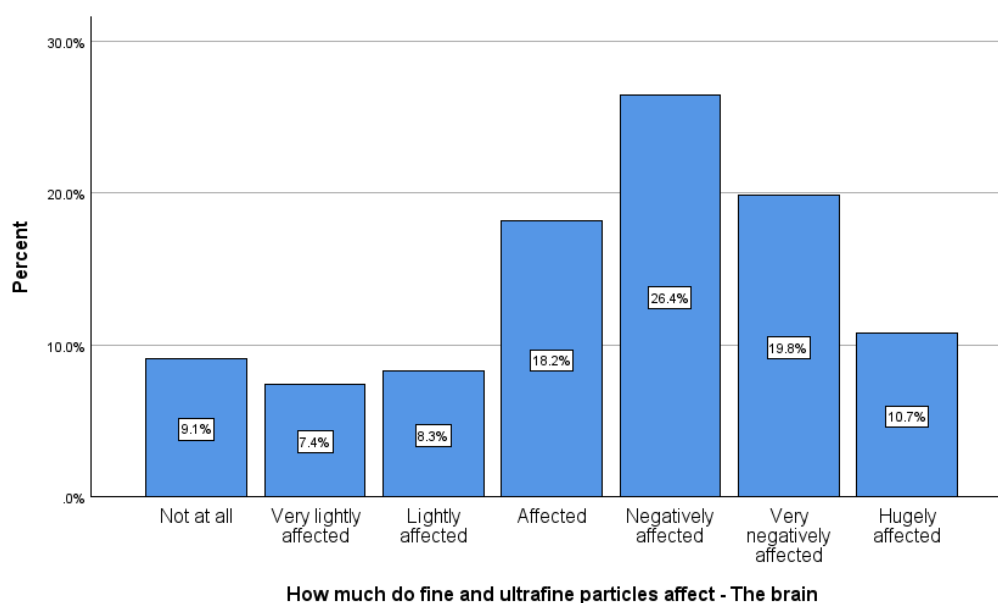
Figure 28 Responses to question How much do fine and ultrafine particles affect – The brain

TRUST IN GOVERNMENT

As observed, there is an overall pattern of distrust regarding the government's commitment to reducing fine and ultra-fine particle pollution, as more people responses fall between 1 and 3 than 5 or over). The mean response score was 3.13 (SD = 1.22), which reflects this sentiment, as evidenced by a higher percentage of extreme negative ratings (25.4%, marking 2 – very untrustful in government commitment, or bellow) compared to extreme positive ones (3.1% making 6 – vey trustful in government commitment, or over).

Figure 29 Results distribution in Trust in Government scale

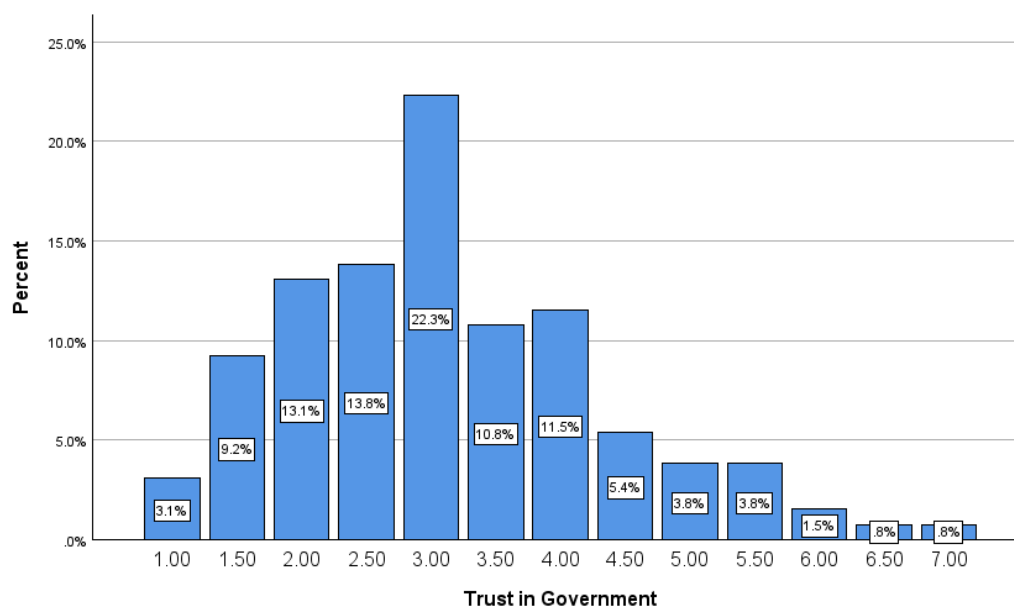The analysis of responses of the scale reveals that most participants perceive politicians as lacking commitment to addressing particle emissions in the municipality. This perception becomes more pronounced as the measures become more specific, such as the reduction of PM2.5 particles. A significant majority of participants rated below the midpoint (63.9%) or at the midpoint (21.5%), with a mean score of 3.08 (SD = 1.50).
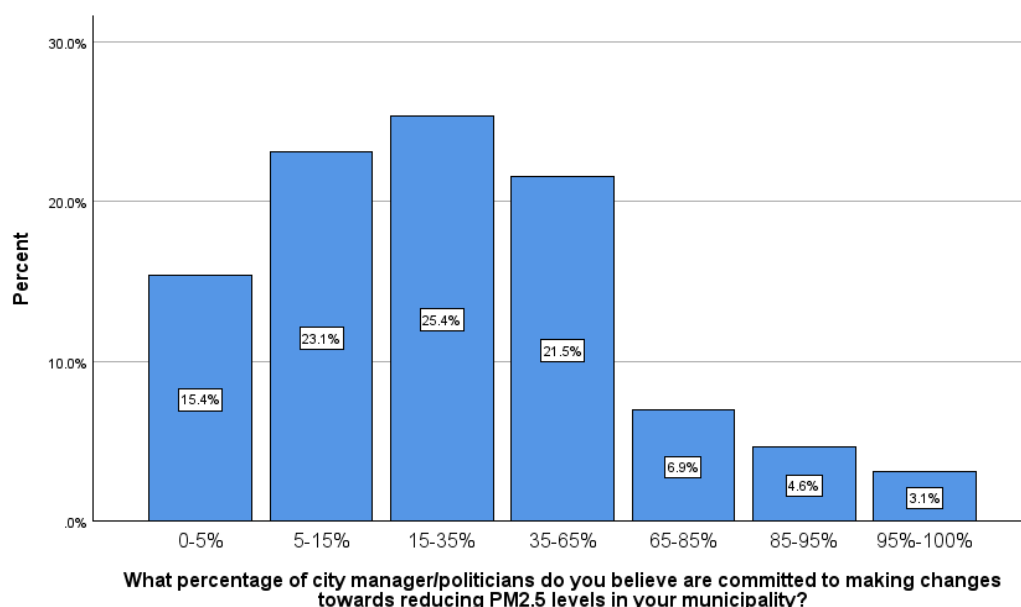
Figure 30 Responses to question What percentage of city manager/politicians do you believe are committed to making changes towards reducing PM2.5 levels in you municipality?

When considering broader measures, such as the general reduction of emissions and improvement of air quality, most participants selected the scale point 3 (38.2%), with a mean score of 3.18 (SD = 1.25).

Figure 31 Responses to question To what extent do you believe politicians are committed to improving air quality and reducing particulate matter emissions, specifically?

ATTITUDES TOWARDS AEROSOLD SOLUTIONS

As shown in the pattern depicted in the next figure, most respondents (74%) rated above the midpoint on the scale (4), indicating an overall positive attitude towards AeroSolfd (M = 4.87, SD = 0.96).
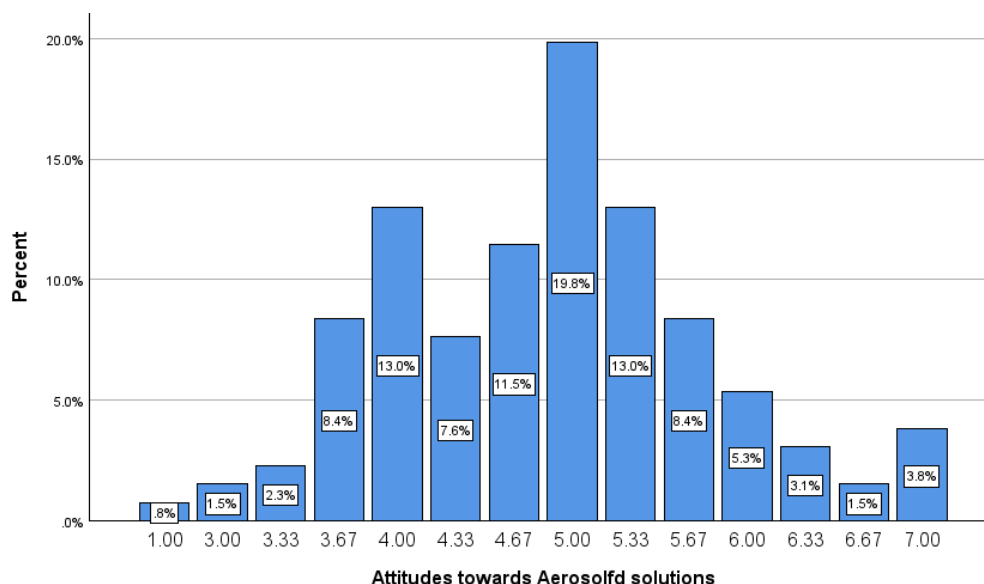
Figure 32 Results distribution in Attitudes towards AeroSolfd solutions scale

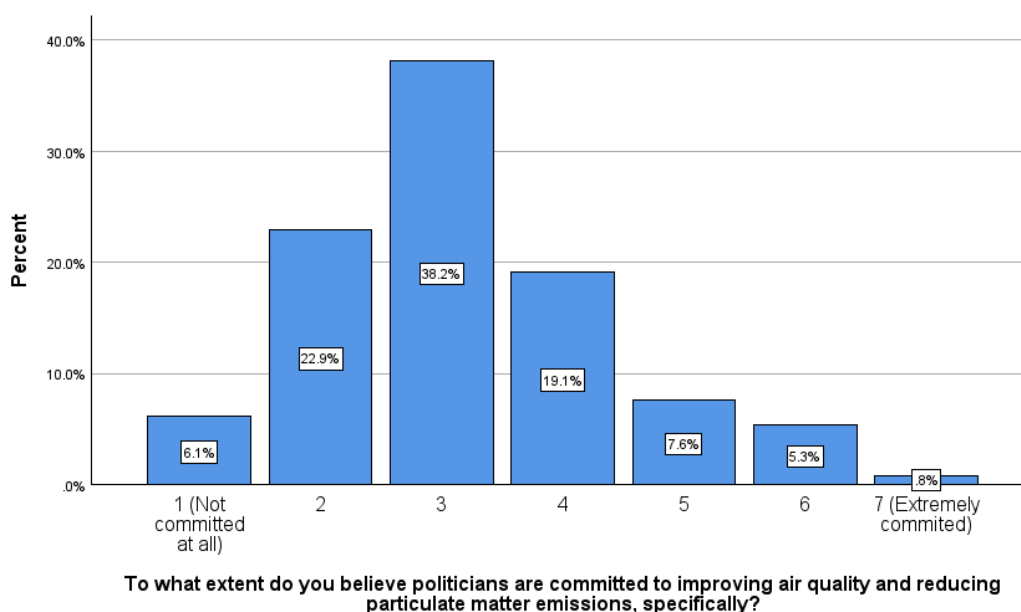Following the general pattern, participants believe that AeroSolfd can have a positive impact on their municipality (M = 4.72, SD = 1.41) and express a generally positive perception of AeroSolfd solutions (M = 4.78, SD = 0.98). However, it is important to note that while the evaluations lean positive, the mean scores remain relatively close to the midpoint of the scale, suggesting a more neutral or reserved stance rather than a strongly positive or negative assessment. This neutrality is further emphasized by the fact that a significant proportion of respondents (42.7%) selected the neutral point when asked about their overall perception.
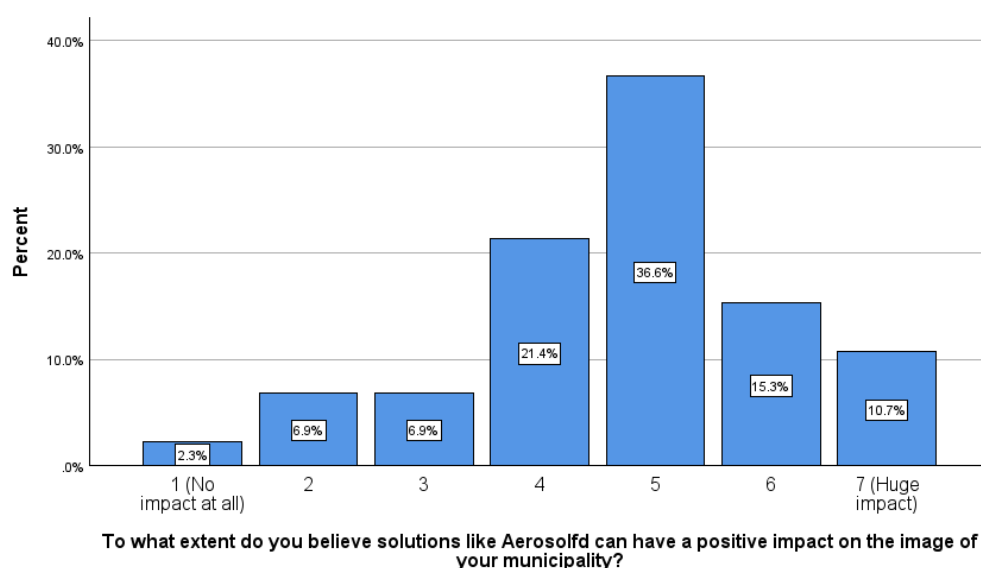
Figure 33 Responses to question To what extent do you believe solutions like AeroSolfd can have a positive impact on the image of you municipality?
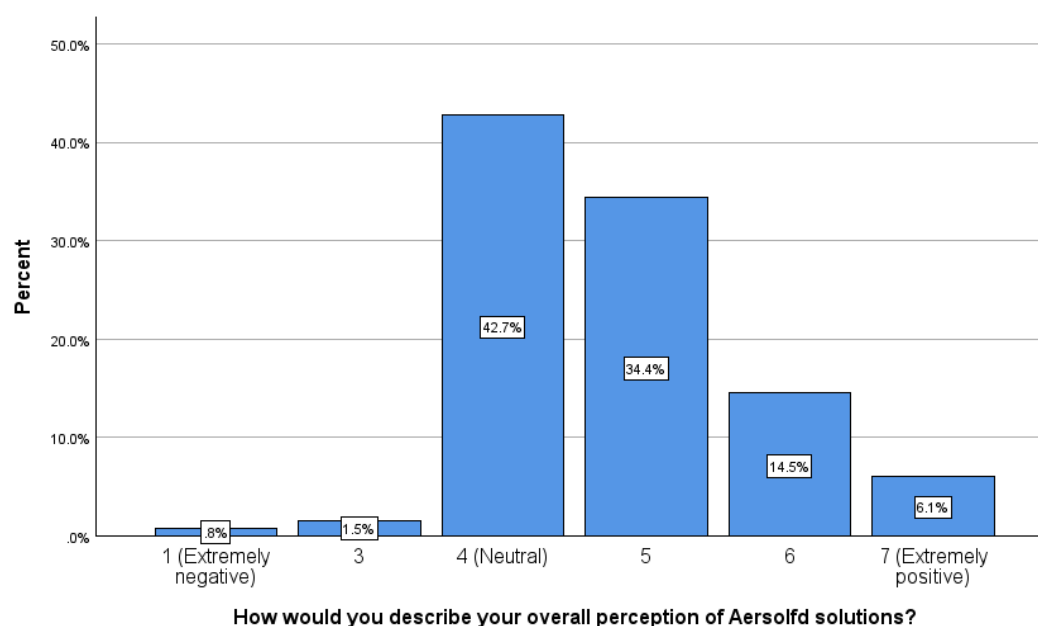
Figure 34 Responses to question How would you describe your overall perception of AeroSolfd solutions

Notably, when respondents were asked specifically about the potential impact of AeroSolfd solutions on air quality and environmental pollution, the attitudes became more favourable (M = 5.10, SD = 1.98), with most participants rating above the midpoint.
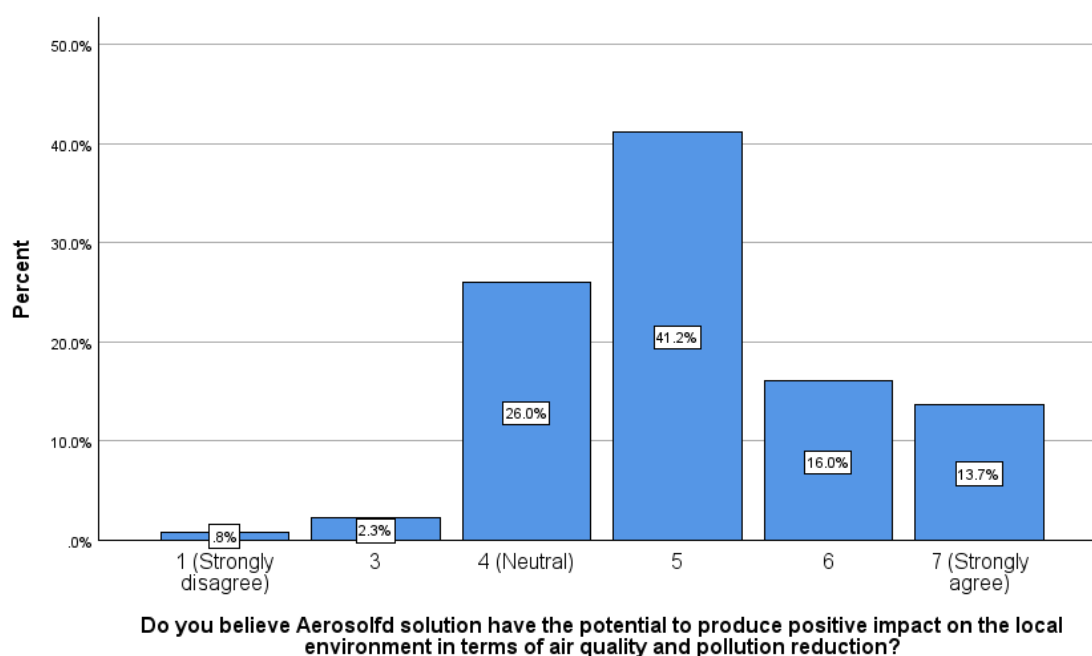
Figure 35 Responses to question Do You believe AeroSofl solution of the potential to produce positive impact on the local environment in terms of air quality and pollution reduction?

ATTITUDES TOWARDS AIR QUALITY IMPROVEMENT IN THE CITIES

Figure 36 illustrates respondents' attitudes toward air quality improvement in cities, measured on a 7-point scale. The distribution reveals that the largest proportion of respondents have moderate to high attitudes in this scale (M = 5.56; SD = .95).

Notably, more positive attitudes are evident, with 8.5% of respondents giving the maximum rating of 7.00 and another 13.1% selecting 6.00. However, lower scores are less frequent, with 1.5% selecting 3.00 and only 0.8% selecting 2.33 or 3.67.
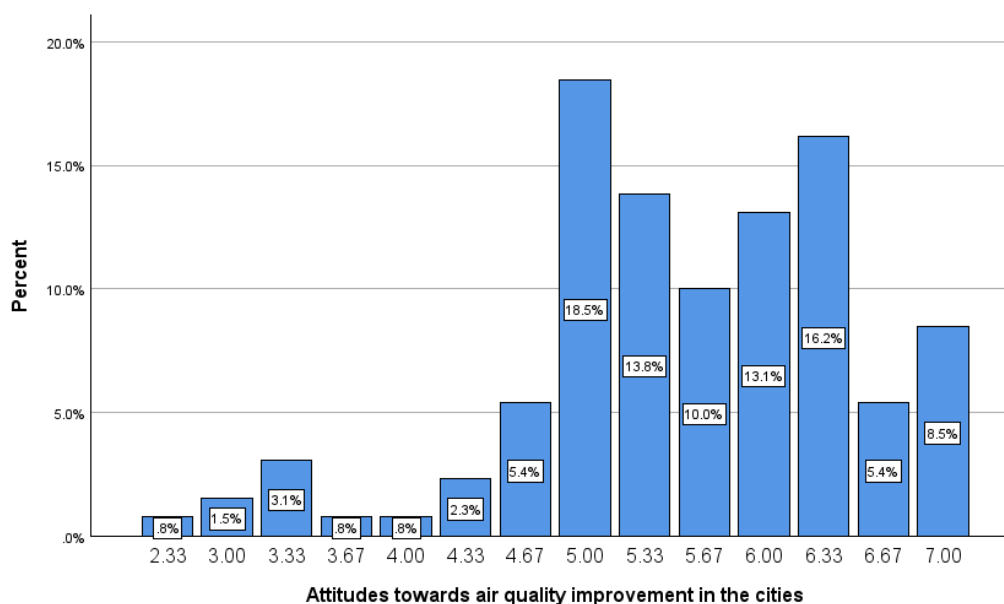
Figure 36 Results distribution in Attitudes towards AeroSolfd solutions scale

By analysing each item of the scale individually, a consistent pattern emerges, with the majority of respondents providing answers at or above the midpoint of the scale (95.5% evaluate AeroSolfd solutions as highly relevant; 92.4% consider air quality as very relevant for the well-being; and 88.5% state that politicians should be much more concerned on improving air quality that they actually are).

This suggests a shared sentiment among participants regarding the importance of air quality for residential living (M = 5.72, SD = 1.24) and acceptance for solutions that reduce emissions (M = 5.72, SD = 1.18), including AeroSolfd solutions in particular. Additionally, there is a prevalent belief that politicians should place greater emphasis on addressing air quality issues (M = 5.24, SD = 1.27).

Figure 37 Responses to question in your opinion how relevant are solutions that reduce transport emissions of particles?

Figure 38 Responses to question On a scale from 1 to 7, how important do you consider air quality for the well-being of residents in your municipality?
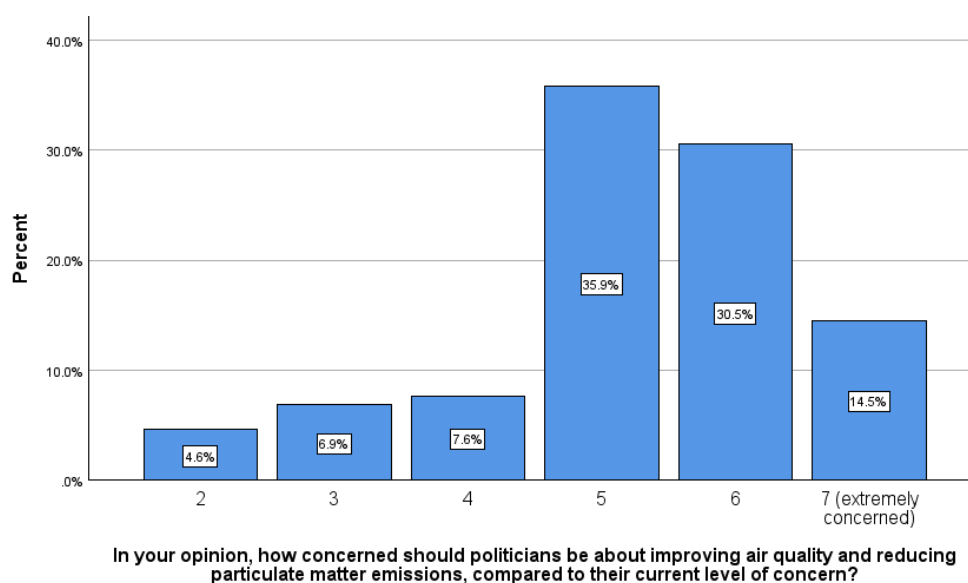
Figure 39 Responses to question In your opinion, how concerned should politicians be about improving air quality and reducing particulate matter emissions, compared to their current level of concern

CORRELATIONS

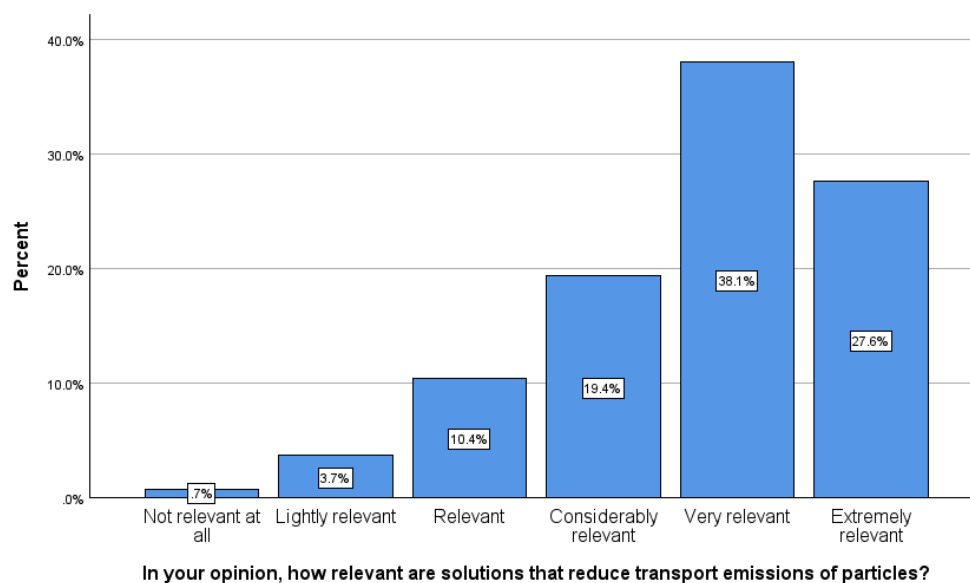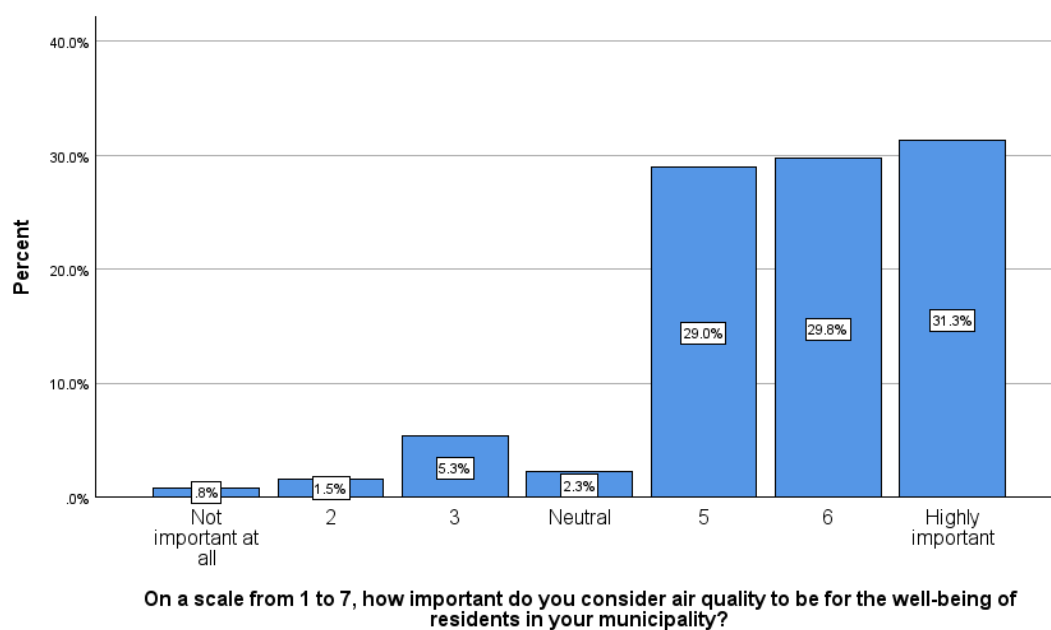The correlations between the scales demonstrates there are significant correlations among all scales, except the one concerning Trust in Government which is only correlated with the attitude towards AeroSolfd solutions.

Table 2 – Correlations between scales

		Perceived municipal air quality	Attitudes towards transport particles	Risk Perception	Trust in Government	Attitude towards AeroSolfd	Attitude towards Improvement
Perceived municipal air quality	r	1	-.334**	-.416**	.037	-.117	-.224*
	p-value		<.001	<.001	.676	.185	.010
Attitudes towards transport particles	r		1	.573**	.020	.435**	.536**
	p-value			<.001	.824	<.001	<.001
Risk Perception	r			1	.090	.327**	.604**
	p-value				.333	<.001	<.001
Trust in Government	r				1	.199*	.160
	p-value					.023	.070
Attitude towards AeroSolfd	r					1	.534**
	p-value						<.001
Attitude towards Improvement	r						1
	p-value						

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

It also shows that people's attitudes towards AeroSolfd solutions is mainly related with the attitude towards improvement of air quality in municipalities (0.534, p<0,01), attitudes towards transport

particles (0.435, p<0,01), risk perception (0.327, p<0,01) and, in a smaller scale, with trust in government (0.199, p<0,05).

But while it seems to be independent of perceived municipal air quality, as it does not correlate with it directly, we can see there is a very strong negative correlation of this perception with risk perception (0.416, p<0,05). and wit attitude towards transport particles (0.334, p<0,05). and a strong negative correlation between this perception and the attitude towards improvement of air quality (0.224, p<0,05). This means that the lower the attitude towards municipal air quality, the higher the risk perception, the worst the attitudes towards transport particles and the higher the need towards improvement of air quality. So it seems there is an indirect effect of perceived municipal air quality over the attitude towards AeroSolfd solutions, through the mediating variables of attitude towards improvement of air quality, risk perception and attitudes towards transport particles.

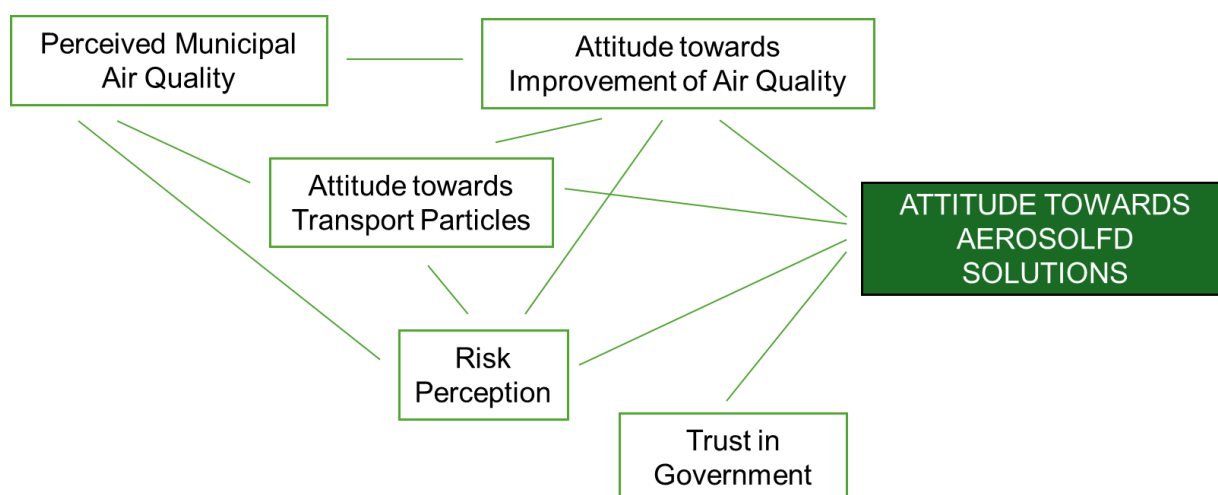The following image displays the relationship among variables.

Figure 40 – Relations between psycho-social variables explaining the attitude towards AeroSolfd solutions

5. CITIZENS' AWARENESS ON LIFE CYCLE ASSESSMENT

5.1. OBJECTIVES AND EXPECTED IMPACT

5.1.1. OBJECTIVES

Life Cycle Assessment is a crucial tool for evaluating the environmental impact of products and processes. Enhancing citizen awareness of LCA can empower individuals and communities to make informed decisions and contribute to sustainable development. This section focuses on the objectives, methodology, and findings from the development and testing of Cyclum Vitae, a serious game designed to raise awareness about Life Cycle Assessment.

The serious game aims at:

1. Increasing awareness of LCA principles and their applications through interactive gameplay.

2. Facilitating understanding of trade-offs in sustainability decisions.

3. Encouraging collaborative and competitive approaches to resource management.

By engaging with groups of diverse stakeholders, including experts in sustainability but also students, researchers, policymakers, and businesses and general public, the expected impact of Cyclum Vitae serious boardgame presented an innovative and replicable model for LCA education. This, in turn creates a space where citizens can understand the implications of product lifecycle decision on the environment.

Citizens play a pivotal role in driving sustainable practices through their consumption patterns, choices, and advocacy for responsible policies. Understanding the environmental impacts of everyday products can empower individuals to:

- Make informed choices about the products they use.
- Advocate for sustainable production practices.
- Participate in community-level initiatives that promote circularity and sustainability.

Despite its importance, LCA remains underutilized and generally unknown by the general public due to its technical nature. Simplifying these concepts and making them relatable is essential to achieving widespread understanding and action.

Cyclum Vitae as an Educational Tool

Figure 41 The back of a Cyclum Vitae boardgame card

Cyclum Vitae is a serious board game designed to simulate the decision-making processes involved in designing sustainable products. The game breaks down the complexities of LCA into manageable, interactive components, offering players insights into the trade-offs and challenges of sustainability.

1. **Simplification of Complex Concepts:**

   - The game introduces LCA stages—raw material extraction, manufacturing, and end-of-life—through tangible gameplay elements such as resource tiles, process cards, and scoring systems.
   - Players interact with key LCA impact categories to understand the implications decision have on the environment and on human health in real-world scenarios. For the Aerosolfd project, the categories chosen within Cyclum Vitae are Climate change [Kg CO2eq], Human Toxicity [1,4-DCB eq] and Particulate matter formation [PM2.5 eq].

2. **Interactive Learning**:

   - Players assume the role of decision-makers tasked with creating a sustainable product while navigating constraints such as cost, resource availability, and environmental impact.
   - The game map, featuring hexagonal territories, encourages strategic thinking as players manage resources and trade with others to meet their production goals.

3. **Scenario-Based Engagement**:

   - Players are presented with dilemmas that mimic real-world challenges, such as whether to choose cheaper, high-impact materials or invest in more sustainable alternatives. Different scenarios or objectives can be deployed with specific constraints or tasks for the players.
   - The scoring system incorporates environmental and economic performance, allowing players to visualize the trade-offs and synergies of their decisions.

4. **Collaborative and Competitive Dynamics**:

- The game fosters discussions and negotiations, reflecting the need of consensus among stakeholders in achieving sustainability.

The Gameplay

Cyclum Vitae challenges players to build a product more sustainably than their competitors by selecting the right materials, processes, and end-of-life strategies. For this the game offers a map, and tiles.

1. **Map Design**:

Figure 42 Cyclum Vitae boardgame map, showing all the available territories (colour-coded)

- The game features a land and water map with a hexagonal grid, divided into territories.
- Players start at a designated territory they can call their own.

2. **Resource Management**:

- Players receive money each round and can purchase tiles for energy production, raw material extraction, or transportation.
- The game features 3 different tile categories:
    o **Energy tiles** : Fossil fuels, solar power, wind power, geothermal power, hydropower
    o **Resource tiles:** Polymers, natural fibres, ore
    o **Transport tiles:** Port, train station, airport
- Specific tiles are required to manufacture goods. For example, a "natural fibres" tile is necessary to produce a rubber card, while an "Ore" tile is required to manufacture steel products (represented by a steel card).
- Players are allowed to trade with other players, but require a transport tile to make it happen.

Figure 43 Example of energy tiles used in Cyclum Vitae boardgame

3. **Card Design:**

- The game features 6 different card types:
  o **Materials cards**: They have information for different materials types that can be extracted/obtained, and include, metal cards, non-metallic cards, natural fibre cards, plastics/polymer cards and composites cards.
  o **Energy, fuels & oils**: They have information for different fuels and oil types, such as benzine (petrol), diesel, LPG. Energy cards have information on electricity and heat, which can potentially be sources from renewable sources.
  o **Process cards**: These cards show the different manufacturing and end-of-life processes available for different materials.
  o **Transport cards:** These cards have information on different transport modes, including their cost and environmental footprint.
  o **Infrastructure cards**: These cards have information for energy infrastructure, such as a solar field, or a wind farm.
  o **Information cards**: Helping cards with extra information for the game
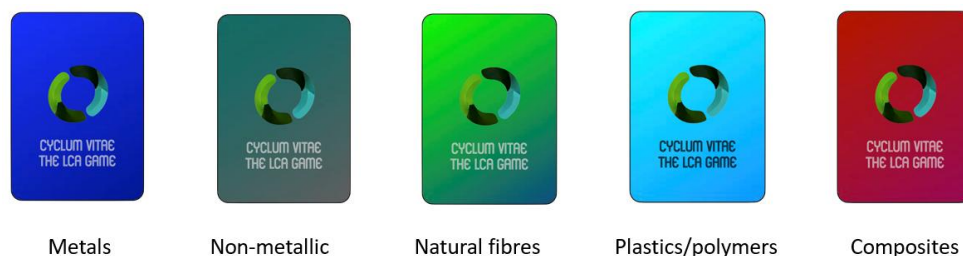
Figure 44 Example of material cards

4. **Product Manufacture**:

- Process cards specify possible pairing cards by colour shown on the left of the card, along with environmental metrics (e.g., climate change impact, human toxicity, and particulate matter emissions) and associated costs.
- Material cards specify environmental metrics (e.g., climate change impact, human toxicity, and particulate matter emissions) and associated costs.
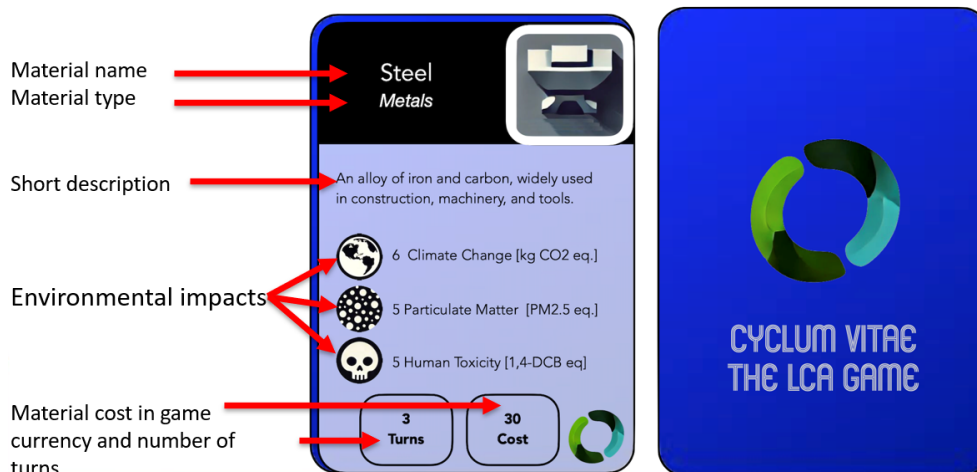
Figure 45 Material card example

5. **Strategic Decision-Making**:

- Players use energy – required for different manufacturing and end-of-life processes, shown by a yellow colour code on the top of the card-, process, and material cards to create and dispose of their products.

-

   - *Figure 46 process card example: Extrusion. Colours on the left show the possible cards that can be paired with the extruding process. Colour on the top show a need for energy card.*

- Decisions involve balancing economic costs, environmental impact, and resource efficiency.

6. **Objective**:

- The winner is the player who successfully builds the most environmentally sustainable product, minimizing ecological footprints while staying competitive.

Figure 48 Example of all the required cards to manufacture and dispose of a wine bottle.

5.2. METHODOLOGY

Games have long been recognized as powerful tools for education and engagement, offering interactive and experiential ways to convey complex concepts. Serious games, in particular, are designed to achieve specific learning objectives.

Many theories can be adopted to the use serious games for learning purposes. The eexperiential Learning Theory (Kolb, 1984) for example, emphasizes active engagement and reflection in learning, a concept embodied in Cyclum Vitae, where players navigate simulated real-world scenarios, making decisions about resource management and sustainability; this process of active experimentation and reflective observation aligns with Kolb's learning cycle by reinforcing the trade-offs between cost and environmental impact. Similarly, Constructivist Learning Theory (Vygotsky, 1978) highlights social interaction in knowledge construction, evident in Cyclum Vitae's collaborative and/or competitive environment that not only encourages, but that requires trade, negotiation as players discuss strategies and share insights about resource management, deepening their understanding of LCA principles.

For the Aerosolfd project, the Cyclum Vitae boardgame developed by Cenex creates then the opportunity to enhance public understanding of Life Cycle Assessment and to raise awareness on sustainability. Table 3 shows the status of the Cyclum Vitae development.

Table 3 Development stages of the Cyclum Vitae game

ACTION	STATUS
Concept development	DONE
Prototype development	DONE
First internal testing	DONE
First round of feedback	DONE
Iterative development	DONE
First external testing	DONE
Second round of feedback	DONE
Further development	DONE
External testing	DONE
Iterative development	IN PROGRESS
Deployment	NOT STARTED

5.2.1. ROUND 1

Cyclum Vitae was developed and tested within Cenex and later a Mobility Fair in Amsterdam. The target audience at the fair included sustainability practitioners, students, researchers, policymakers, and businesses interested in sustainable mobility. During that first external round feedback was collected and the game suffered minor modifications to improve playability while retaining the essence of LCA thought integration.

Figure 49 Round 1 of the Cyclum Vitae at the Mobility Fair, Amsterdam

5.2.2. ROUND 2

A second round of testing was carried out in the UK with mobility experts. During this round players showed a better understanding of how their choices impact the environment, however, the feedback received encouraged a streamlining of the game.

The interactive nature of the game kept participants engaged while fostering critical thinking about environmental issues, however the length of the game proved to be longer than expected. Keeping in mind the game can be used for raising awareness in a single session, the game needs to b played in under an hour. This valuable feedback was then implemented into the game, facilitating "light "play versions that fulfill the under-the-hour requirement.

Figure 50 Round 2 of the Cyclum Vitae game testing

5.3 RESULTS AND RECOMMENDATIONS

Feedback from participants highlighted the game's effectiveness in:

- Breaking down the complexity of LCA into relatable scenarios.
- Encouraging collaborative learning and discussion.

Suggestions for improvement included simplifying certain rules further and incorporating additional real-world case studies for context.

Using Cyclum Vitae to introduce citizens to LCA has proven to be an effective strategy for raising awareness about sustainability. By "gamifying" the lifecycle approach, we not only educated participants about environmental impacts but also inspired them to take actionable steps toward sustainable living.

To further enhance citizen awareness of LCA the following actions are required:

1. Expand the use of interactive tools like Cyclum Vitae in educational programs.

2. Develop complementary resources, such as workshops and online modules, to reinforce learning.

3. Facilitate partnerships with schools, community groups, and local governments to integrate sustainability education into broader initiatives.

6. CONCLUSIONS

This report evidences the multiple paths AeroSolfd considered for engaging the public on research activities. While some activities better fit the description of citizen-science, it is important to emphasise all the activities presented in this report raised awareness about the effect of fine particles in human health and enhanced the critical thinking of different groups of stakeholders concerning air quality and AeroSolfd solutions.

The participation of the public has a significant impact in the AeroSolfed project namely through the following contributions:

- Improved communication messages;
- Insights on market acceptance of solutions, main barriers and facilitators;
- Information on how to better reach different groups of stakeholders including lay people
- Improved tool for raising awareness about life cycle assessment

BIBLIOGRAPHY

Willig, C. (2013). Introducing qualitative research in psychology (3rd ed.). Open University Press.

Kolb, D. A. (1984): Experiential Learning: Experience as the Source of Learning and Development. Prentice-Hall.

Vygotsky, L. S. (1978): Mind in Society: The Development of Higher Psychological Processes. Harvard University Press.