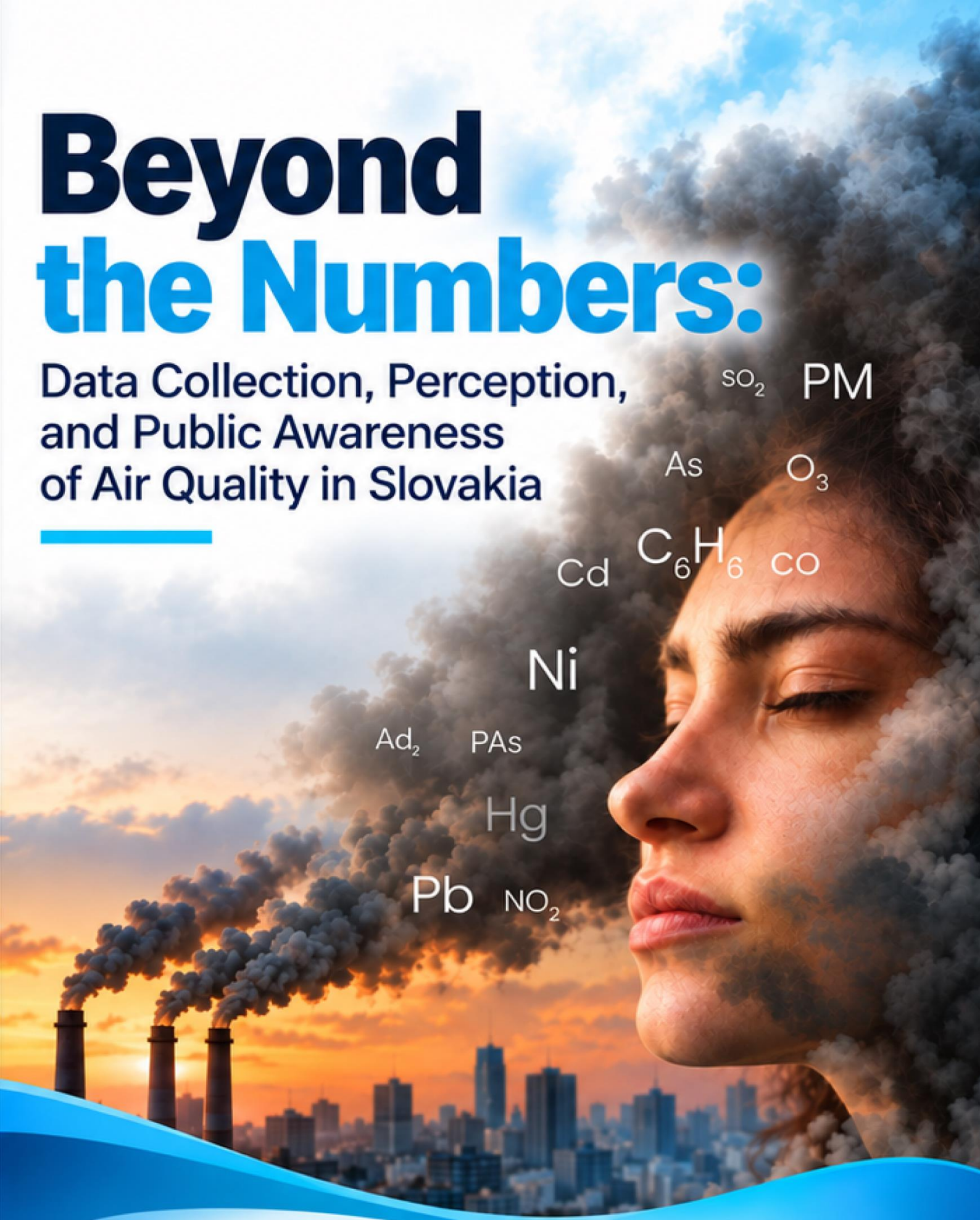
Beyond the Numbers:

Data Collection, Perception, and Public Awareness of Air Quality in Slovakia



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Introduction

Air quality has emerged as one of the most pressing public health and environmental challenges of the twenty-first century. Beyond its direct ecological consequences—ranging from soil acidification to the disruption of delicate aquatic ecosystems—atmospheric pollution represents an invisible yet pervasive determinant of human well-being, life expectancy, and socioeconomic stability. While conventional environmental discourse has historically relied on technical metrics, sensor outputs, and regulatory emission inventories, these empirical figures often fail to capture the complex societal reality on the ground. Purely quantitative approaches, while indispensable, frequently stop at the boundary of documentation, leaving a significant gap between scientific measurement and community action.

This monograph, titled *Beyond the Numbers: Data Collection, Perception and Public Awareness of Air Quality in Slovakia*, addresses this critical divide. Published as part of the Erasmus+ Cooperation Partnerships project VISIONAIR (*Increasing the Visibility and Knowledge Base on Air Quality With Big Data and Its Impact on the Population Health*, No. 2023-1-SK01-KA220-HED-000158470), this work integrates rigorous data collection methodologies with the vital human dimension of environmental risk: public perception, awareness, and behavioral response.

Focusing on the national context of Slovakia within broader European policy frameworks such as the European Green Deal and the Zero Pollution Action Plan the monograph examines how systemic vulnerabilities, demographic aging, and socioeconomic disparities magnify environmental exposure risks. Susceptible populations, particularly children and the elderly, bear a disproportionate burden of chronic cardiopulmonary and systemic ailments linked to atmospheric pollutants. Yet, protective behavioral adjustments, community-level mitigation, and compliance with health advisories fundamentally depend on how individuals perceive and understand the invisible hazards around them. By contrasting objective monitoring data with subjective public awareness, this work identifies structural blind spots in contemporary environmental communication.

Ultimately, *Beyond the Numbers* serves as an essential bridge linking environmental engineering, public health, and social sciences. It equips researchers, municipal decision-makers, and educators with the empirical and conceptual tools required not only to measure atmospheric contaminants accurately, but to foster an informed, engaged citizenry. By contextualizing raw data within public understanding and participatory governance, this volume advocates for policies that transcend passive reporting, driving forward evidence-based interventions for cleaner air and healthier communities across Slovakia and Europe.

Authors

1 Theoretical Overview

1.1 Air Quality: Monitoring, Health Impacts and Socio-Economic Perspectives

Professional scientific articles on air quality address a broad spectrum of subjects, ranging from the fundamental processes of pollution to its impacts on health, climate, and ecosystems (Vallero, 2014; Chow, 2006). Air quality is a critical environmental and health concern that impacts human well-being, ecosystems, and overall quality of life. Air pollution originates from various sources, including industrial activities, transportation, energy production, agriculture, and natural events like wildfires and volcanic eruptions (Cohen et al., 2015). Much of the research is dedicated to international initiatives and policy frameworks to enhance air quality. Organizations like the World Health Organization (WHO) and the United Nations Environment Program (UNEP) establish global standards and guidelines to coordinate and unify the efforts of various countries in improving air quality (Beloconi et al., 2024). Research also emphasizes the impact of air pollution on human health, often revealing a connection between exposure to pollutants like particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and ground-level ozone, and a higher incidence of diseases such as asthma, chronic obstructive pulmonary disease (COPD), cardiovascular disease, and lung cancer. Some studies also explore how long-term exposure to air pollution reduces life expectancy and premature mortality (Joshi et al., 2024; Lelieveld et al., 2015).

Lastly, scientific articles also concentrate on the advancement of new technologies and strategies to enhance air quality (Castell et al., 2017; Shi et al., 2016). This includes the creation of cleaner combustion technologies, the more efficient utilization of renewable energy sources, and the enhancement of air pollution monitoring systems. Beyond technical solutions, these studies also investigate political and regulatory approaches, such as implementing emission limits, promoting sustainable transportation, and improving urban planning to reduce pollution (Göbel et al., 2022). Scientific studies frequently explore and enhance methods for monitoring air quality. Researchers are developing new sensors and technologies that allow more accurate and cost-effective real-time measurement of pollutants. Additionally, satellite imagery and drones are increasingly employed to monitor air quality across large geographic areas, identifying pollution sources and analyzing their dispersion (Achieng & Andala, 2024; Ma et al., 2020).

1.2 European Institutional Framework (EEA and Eionet), Greenhouse Gases and Climate Interaction

The main reliable source for data collection, acquisition and implementation of relevant analyses and gain of new knowledge for the needs of fulfilling project goals of Increasing the Visibility and Knowledge Base on Air Quality with Big Data and Its Impact on the Population Health is the European Environment Agency EEA (www.eea.europa.eu). The EEA is an agency of the European Union. Together with our knowledge Eionet network provides the knowledge and the data needed to achieve sustainability in Europe. The European Environment Agency (EEA) provides valuable insights on the state of Europe's environment. Thanks to reliable data collected from extensive network actively supports Europe´s environment and climate policies. EEA collects and validates data from reliable sources to analyze trends and produce policy-relevant analyses on environment and climate topics. EEA works in close cooperation with a multitude of organizations at European, regional and global levels. Its knowledge network EIONET (European Environment Information and Observation Network) is their main partner and brings together 38 member countries (include the 27

European Union Member States, Iceland, Liechtenstein, Norway, Switzerland and Turkey and 6 West Balkan cooperating countries; these include Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia and Kosovo). Eionet was founded in 1994 and is a well-known and trusted provider of high-quality data, information and sustainability assessments for Europe. Eionet is bringing together around 2,000 experts from more than 400 national institutions that have expertise in environmental issues. Vision of EEA and Eionet: The EEA and Eionet will enable a sustainable Europe through trusted and actionable knowledge for informed decision-making on priorities and solutions, in line with Europe's policy ambitions. EEA and Eionet prepared a strategy for the years 2021 to 2030 to provide data and knowledge in the fields of environment and climate (EEA, 2024).

Greenhouse gases (also known as GHGs) are gases that occur in the Earth's atmosphere and absorb long-wave infrared radiation, which warms the lower atmosphere and the Earth's surface. The most significant gases that cause global warming via the greenhouse effect are the following (EEA, 2024):

- Carbon dioxide: 76 % (EEA, 2024)
- Methane: 16 % (EEA, 2024)
- Nitrous oxide: 6 % (EEA, 2024)
- Fluorinated gases: 2 % (EEA, 2024)

Water vapor reacts to temperature changes, is referred to as a feedback, because it affects the climate in different ways. Some remain in the atmosphere for a long time, but do not cause as much warming per kilogram of emissions as carbon dioxide, for example. Others, like methane, warm the Earth a lot but don't stay in the atmosphere very long (Bond et al., 2013; Höglund-Isaksson et al., 2017). There is a so-called exchange rate that allows comparison of different gases. The exchange rate expresses how much a kg of carbon dioxide emissions warms the climate in the same way as 1 kg of another greenhouse gas. The exchange rate is called Global Warming Potential according to UNFCCC (United Nations Framework Convention on Climate Change, signed by 154 countries at the Rio de Janeiro summit in 1992). The following data from the EU's Total greenhouse gas emissions and removals are based on data reported by EU Member States under the EU Governance Regulation (European Environment Agency, Greenhouse gases viewer, 2024).

1.3 Air Pollution Trends and Statistics in Europe

Although air quality in Europe has improved over recent decades, air pollution remains a significant environmental and health challenge. Climate change can exacerbate air pollution levels, particularly by increasing ozone formation (Air quality in Europe, 2021). Combatting air pollution is, therefore, a central priority in EU policy, as reflected in initiatives like the European Green Deal, which aims to lower emissions and enhance air quality across Europe. According to the European Environment Agency (EEA), the primary air pollutants include fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and ozone (O_3). The European Union has been actively working to improve air quality for several decades, focusing on reducing emissions from various sectors, promoting sustainable transportation, and decreasing reliance on fossil fuels (Beloconi & Vounatsou, 2023; Manders & Ketzel, 2023).

Despite the progress made, Europe continues to face significant challenges related to air pollution:

- *Climate Change:* Rising temperatures due to climate change can lead to increased ground-level ozone formation and exacerbate air pollution issues. To address this interconnected challenge effectively, it is crucial to align measures for improving air quality with climate change policies (Fiore et al., 2015; Bind et al., 2016).
- *Traffic Density and Urbanization:* The growth of urban areas and high traffic volumes in cities contribute to elevated levels of air pollution. While initiatives like low-emission zones and the promotion of public transportation are essential, further action is required to manage and mitigate pollution effectively (Viana et al., 2020).
- *Internationalization:* Air pollution crosses national boundaries, making international cooperation essential. The EU is actively collaborating with non-EU countries to tackle cross-border air pollution issues and coordinate efforts for cleaner air (Guerreiro et al., 2014; Manders & Ketzel, 2023).

The pollution levels are based on the annual mean values for NO_2, $PM_{2.5,}$ and PM_{10} , while they are based on the annual maximum 8-hour running average for O_3 (European Environment Agency, Air quality reporting for public portal, 2024).

2 Problematic Aspects of Air Pollution and Monitoring Methodologies

2.1 Characterization of Major Pollutants

Air pollution is multifaceted, with various pollutants interacting in complex ways that can exacerbate their harmful effects. The most common pollutants include particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOC_s), and ozone (O_3). Each of these pollutants has distinct sources, behaviors in the atmosphere, and health impacts, making air pollution a challenging issue to address comprehensively.

- *Particulate Matter (PM):* Particulate matter, especially $PM_{2.5}$ (particles with a diameter of 2.5 micrometers or smaller), is one of the most dangerous forms of air pollution (Pope & Dockery, 2006). These tiny particles can penetrate deep into the lungs and even enter the bloodstream, leading to a range of health issues, including respiratory infections, heart disease, and lung cancer. PM is generated from various sources, including vehicle emissions, industrial activities, construction sites, and residential heating.
- *Nitrogen Oxides (NO_x):* Nitrogen oxides, primarily NO and NO_2, are major contributors to air pollution (Shcheklein & Dubinin, 2020). They are produced mainly by the combustion of fossil fuels in vehicles, power plants, and industrial facilities. NO_x plays a crucial role in the formation of ground-level ozone and fine particulate matter, both of which have significant health and environmental impacts. Furthermore, NO_x contributes to acid rain and eutrophication in aquatic ecosystems.
- *Sulfur Dioxide (SO_2):* Sulfur dioxide is primarily produced by the burning of fossil fuels containing sulfur, such as coal and oil. It is a precursor to acid rain, which can damage forests, soils, and aquatic environments (Ku et al., 2017). SO_2 also contributes to respiratory problems and aggravates conditions such as asthma and bronchitis.
- *Carbon Monoxide (CO):* Carbon monoxide is a colorless, odorless gas that is produced by incomplete combustion of carbon-containing fuels (Roderique et al., 2015). High levels of CO can be deadly, as it interferes with the blood's ability to carry oxygen. Even at lower levels, prolonged exposure can cause harmful effects, particularly for people with heart disease.

- *Volatile Organic Compounds (VOCs):* VOCs are a group of organic chemicals that easily evaporate into the air. They are emitted from a wide range of sources, including vehicle exhaust, industrial processes, and household products like paints and cleaning agents. VOC_s can react with NO_x to form ground-level ozone, a major component of smog.
- *Ozone (O_3):* While ozone in the upper atmosphere protects us from harmful ultraviolet radiation, ground-level ozone is a harmful pollutant (Nguyen et al., 2022). It is formed by the reaction of VOC_s and NO_x in the presence of sunlight. Ozone is a powerful respiratory irritant and can exacerbate conditions such as asthma and bronchitis. It also affects vegetation, leading to reduced agricultural yields and forest health.

3 Measurement Methods and Analytical Procedures

3.1 Direct Measurement Techniques

Air pollution measurement methods can be broadly classified into two categories: direct measurement techniques and indirect measurement techniques. Direct methods involve the immediate sampling and analysis of air pollutants, while indirect methods rely on instruments or models to infer pollutant concentrations based on other observed variables. Direct measurement techniques are the cornerstone of air pollution monitoring. These methods involve the collection of air samples followed by chemical or physical analysis to determine the concentration of specific pollutants.

- **Gravimetric Method:** The gravimetric method is primarily used to measure particulate matter (PM) in the air. Air is drawn through a filter that captures particulates, and the filter is then weighed before and after sampling. The difference in weight, adjusted for the volume of air sampled, provides the concentration of particulate matter. This method is widely recognized for its accuracy but requires careful calibration and control to ensure precise results (Artiola et al., 2004; Noble et al. 2001).
- **Gas Chromatography (GC):** Gas chromatography is a method used to separate and analyse compounds that can be vaporized without decomposition. In air pollution monitoring, GC is often used to measure volatile organic compounds (VOC_s) and other gaseous pollutants. A sample of air is injected into the chromatograph, where it is carried by an inert gas through a column that separates the different compounds based on their chemical properties. The separated compounds are then detected, typically by a flame ionization detector (FID) or a mass spectrometer (MS). GC is highly sensitive and capable of detecting a wide range of pollutants, but it requires complex and expensive equipment (Ras et al, 2009).
- **Spectroscopic Methods:** Spectroscopic techniques, such as UV-visible spectroscopy, infrared spectroscopy, and fluorescence spectroscopy, are used to measure concentrations of specific gases in the air, such as ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). These methods rely on the principle that different gases absorb light at specific wavelengths. By measuring the absorption of light at these wavelengths, the concentration of the gas in question can be determined. Spectroscopic methods are fast, non-destructive, and can provide continuous monitoring data, but they may require calibration and are sometimes affected by interference from other substances (Platt et al., 2008).
- **Electrochemical Sensors:** Electrochemical sensors are commonly used for the detection of gases such as carbon monoxide (CO), nitrogen oxides (NO_x), and ozone

(O_3). These sensors operate by measuring the current generated by the redox reactions of the target gas at an electrode surface. The current is proportional to the concentration of the gas in the air. Electrochemical sensors are compact, relatively low-cost, and provide real-time data, making them suitable for portable or distributed monitoring networks. However, they may have limited sensitivity and specificity, and their performance can degrade over time (Stetter & Li, 2008).

- **Chemiluminescence:** Chemiluminescence is a method used to measure nitrogen oxides (NO and NO_2) in the atmosphere. The technique involves the reaction of NO with ozone, which produces an excited state of nitrogen dioxide that emits light as it returns to its ground state. The intensity of the emitted light is proportional to the concentration of NO in the sample. By converting NO_2 to NO (typically using a heated converter), the total concentration of NO_x can be determined. This method is highly sensitive and widely used in regulatory monitoring but requires careful calibration and maintenance (European Committee for Standardization, 2012).

3.2 Indirect Measurement Techniques and Modelling

Indirect measurement techniques estimate pollutant concentrations based on observed or measured environmental variables. These methods include remote sensing, dispersion modelling, and proxy measurements.

- **Remote Sensing:** Remote sensing techniques involve the use of satellites, aircraft, or ground-based instruments to detect and measure air pollutants over large areas. These methods can provide valuable information about the spatial distribution of pollutants and are particularly useful for monitoring pollutants that are difficult to measure directly, such as ground-level ozone or particulate matter over wide regions (Martin, 2008).
    - *LIDAR (Light Detection and Ranging):* LIDAR is a remote sensing technique that uses laser pulses to measure the distance to an object or surface. In air pollution monitoring, LIDAR can be used to measure the concentration of aerosols or gases in the atmosphere by detecting the backscattered light from the laser pulse. The technique provides high-resolution vertical profiles of pollutants and can be used to monitor the dispersion of pollutants in the atmosphere. LIDAR systems are highly accurate and can cover large areas, but they are expensive and require skilled operation (Weitkamp, 2005).
    - *DOAS (Differential Optical Absorption Spectroscopy):* DOAS is another remote sensing technique that measures the concentration of trace gases in the atmosphere by analyzing the absorption of light at specific wavelengths. The technique is based on the fact that different gases absorb light differently depending on the wavelength. By comparing the absorption spectra of a light beam that has passed through the atmosphere to a reference spectrum, the concentration of the target gas can be determined. DOAS is widely used for monitoring pollutants such as NO_2, SO_2, and O_3, and can provide continuous monitoring over large areas (Platt &Stutz, 2008).
- **Dispersion Modelling:** Dispersion modelling (Zannetti, 1990) is an indirect method that uses mathematical models to predict the concentration of pollutants at different locations based on emission sources, meteorological data, and topographical information. These models simulate the transport, dispersion, and transformation of pollutants in the atmosphere.

- *Gaussian Plume Models:* Gaussian plume models are widely used for predicting the dispersion of pollutants from point sources, such as industrial stacks. These models assume that pollutants disperse in a plume that has a Gaussian distribution in both the horizontal and vertical directions. The concentration of pollutants at any point downwind of the source can be calculated based on the emission rate, wind speed, and atmospheric stability. Gaussian models are relatively simple and computationally efficient, making them suitable for regulatory purposes, but they may not accurately represent complex terrain or atmospheric conditions (Seinfeld & Pandis, 2016).
- *Computational Fluid Dynamics (CFD) Models:* CFD models provide a more detailed and accurate representation of pollutant dispersion by solving the equations of fluid motion (Navier-Stokes equations) for the atmosphere. These models take into account the effects of terrain, buildings, and other obstacles on air flow and pollutant dispersion. CFD models can provide high-resolution predictions of pollutant concentrations in complex environments, but they require significant computational resources and expertise to implement (Tominaga & Stathopoulos, 2013; Blocken et al., 2007).

- **Proxy Measurements:** Proxy measurements involve using easily measurable variables as indicators or proxies for pollutant concentrations. For example, temperature, humidity, and wind speed are often used as proxies for predicting ozone levels, as these factors influence the formation of ozone in the atmosphere. Similarly, visibility measurements can be used as a proxy for particulate matter concentrations, as high levels of PM often reduce visibility. While proxy measurements are not as accurate as direct measurements, they can provide useful information in situations where direct measurements are not feasible (Bäumer et al., 2008; Camalier et al., 2007).

3.3 Sampling Procedures, Quality Control, and Validation

The effectiveness of air pollution monitoring depends not only on the choice of measurement method but also on the sampling and analysis procedures used. Proper sampling techniques ensure that the collected data accurately represent the air quality in the monitored area.

- **Sampling Techniques:**
  - *Active Sampling:* Active sampling involves drawing air through a filter or sorbent material using a pump or fan. The collected sample is then analyzed in a laboratory to determine the concentration of pollutants. Active sampling is commonly used for measuring particulate matter, gases, and VOC_s. This method allows for precise control over the sampling rate and duration, but it requires power and maintenance of the sampling equipment (Harper, 2000).
  - *Passive Sampling:* Passive sampling relies on the natural diffusion of pollutants to a collection medium, such as a filter or absorbent material. Passive samplers do not require a power source and are often used for long-term monitoring of pollutants like NO_2, SO_2, and ozone. They are easy to deploy and can be left in the field for extended periods. However, passive sampling generally provides lower time resolution and may be less accurate than active sampling (Kot-Wasik et al., 2007).
- **Calibration and Quality Control:** Calibration and quality control are essential components of air pollution measurement to ensure the accuracy and reliability of data. Calibration involves adjusting the measurement instrument to provide a known

response to a standard concentration of the target pollutant. Regular calibration against certified standards is necessary to account for potential drifts in sensor performance over time. Quality control procedures, such as regular maintenance of equipment, cross-checking with reference methods, and periodic data validation, are also critical to maintaining data integrity (Perez-Ballesta, 2006).

- **Data Analysis:** After sampling, the collected data must be processed and analyzed to extract meaningful information. This process involves several steps, including data cleaning, statistical analysis, and interpretation. Data cleaning involves removing outliers, correcting for sensor drift, and ensuring consistency in the data set. Statistical analysis may include calculating averages, trends, and exceedances of regulatory limits. Finally, data interpretation involves relating the measured pollutant concentrations to potential sources, health impacts, and regulatory standards (Carslaw, & Ropkins, 2012).

4 Measurement Risks and Specifics

4.1 Technical and Environmental Measurement Complexities

Air pollution measurement involves several techniques and methods, each with its own set of complexities and challenges. Understanding the specifics of these methods is essential for recognizing the associated risks and ensuring accurate data collection.

- **Complexity of Pollutant Mixtures:** Air pollution is rarely composed of a single pollutant. Instead, it typically consists of complex mixtures of various pollutants, including particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), volatile organic compounds (VOC_s), and heavy metals. These pollutants can interact in the atmosphere, leading to secondary pollutants such as ozone and fine particulate matter. The complexity of these mixtures poses significant challenges for accurate measurement, as different pollutants require different detection methods, and their interactions can complicate the interpretation of results (Seinfeld & Pandis, 2016).
- **Temporal and Spatial Variability:** Air pollutant concentrations can vary significantly over time and space due to factors such as weather conditions, traffic patterns, industrial activities, and natural events. Temporal variability includes diurnal and seasonal fluctuations, while spatial variability can occur on scales ranging from local to regional. This variability makes it challenging to obtain representative measurements, as a single monitoring station may not capture the full extent of pollution across a larger area. Additionally, short-term measurements may not accurately reflect long-term trends, leading to potential misinterpretations of air quality data (Gulliver & Briggs, 2004).
- **Interference and Cross-Sensitivity:** Many air pollution measurement techniques are susceptible to interference from other substances in the air. For example, electrochemical sensors used to detect gases like NO_2 and CO may respond to other gases, leading to false positives or inaccurate readings. Similarly, spectroscopic methods may be affected by the presence of water vapor or other atmospheric components that absorb light at similar wavelengths as the target pollutant. Cross-sensitivity is a common issue in multi-pollutant environments, where the presence of multiple gases or particulates can complicate the detection of specific pollutants. Properly accounting for and mitigating interference is essential for obtaining accurate measurements (Lewis et al., 2016; Spinelle, 2015).

4.2 Systematic Vulnerabilities and Error Factors

The risks associated with air pollution measurement stem from various sources, including environmental conditions, technological limitations, human error, and data interpretation challenges. These risks can compromise the quality of the data collected and, in turn, affect the decisions made based on that data.

- **Environmental Risks:** Environmental factors such as temperature, humidity, wind speed, and atmospheric pressure can significantly impact the accuracy of air pollution measurements. For example, high humidity levels can affect the performance of particulate matter sensors by causing particles to clump together, leading to an underestimation of PM concentrations. Similarly, temperature fluctuations can alter the response of electrochemical sensors, leading to measurement errors. Wind speed and direction also play a critical role in pollutant dispersion, making it challenging to measure pollution levels accurately at a fixed location. In addition, atmospheric pressure variations can affect the flow rate of air sampling pumps, leading to inconsistencies in the collected data (Jayaratne et al., 2018; Popoola et al., 2016).
- **Technological Risks:** Technological risks are associated with the limitations and potential failures of the instruments and sensors used in air pollution measurement. These risks include:
    - *Instrument Drift:* Over time, sensors and instruments can experience drift, where their response to pollutants gradually changes, leading to inaccurate readings. Drift can result from sensor aging, environmental exposure, or chemical contamination. Regular calibration and maintenance are required to mitigate this risk, but failure to do so can lead to significant errors in the data.
    - *Sensor Failure:* Sensors may fail due to mechanical breakdown, electrical faults, or software malfunctions. Such failures can lead to data gaps or erroneous readings, which may go unnoticed if proper quality control measures are not in place. Sensor failure is particularly problematic in remote or inaccessible locations, where timely repairs or replacements may be challenging.
    - *Data Transmission and Storage:* Many modern air pollution monitoring systems rely on wireless data transmission and cloud storage. However, these systems are vulnerable to risks such as data loss, corruption, or unauthorized access. Cybersecurity threats, network failures, and software bugs can all compromise the integrity of the data collected, leading to potential misinterpretation or misuse (Castell et al., 2017; Mijling, 2018).
- **Human Error:** Human error is a significant risk factor in air pollution measurement. Errors can occur at various stages of the measurement process, including instrument setup, data recording, and analysis. Incorrect setup or calibration of instruments can lead to systematic errors in the data. For example, improper placement of sensors (e.g., too close to a pollution source or too far from the area of interest) can result in non-representative measurements. Mistakes in data analysis, such as misapplication of statistical methods or incorrect interpretation of trends, can compromise the conclusions drawn from the data.
- **Interpretation Risks:** The interpretation of air pollution data is fraught with challenges and potential pitfalls. Misinterpretation of the data can lead to incorrect conclusions and, consequently, inappropriate policy decisions or public health responses. Interpretation risks include over-reliance on single data points,

misinterpretation of causality, and inadequate consideration of measurement uncertainty (European Parliament and Council, 2008).

4.3 Risk Mitigation Strategies

To ensure the accuracy and reliability of air pollution measurements, it is essential to implement strategies for mitigating the risks associated with the process. These strategies include:

- *Robust Calibration and Maintenance Protocols:* Regular calibration of instruments against certified standards is critical for maintaining accuracy. Implementing a strict maintenance schedule, including cleaning, replacing worn parts, and updating software, helps prevent instrument drift and sensor failure. Additionally, using redundancy in measurement systems (e.g., deploying multiple sensors to monitor the same pollutant) can help identify and correct for potential errors.
- *Comprehensive Quality Control Measures:* Quality control measures should be integrated into every stage of the measurement process, from instrument setup to data analysis. These measures include routine checks, cross-validation with alternative methods, and periodic audits of the data collection process. Automated systems for real-time monitoring of instrument performance can also help detect and address issues promptly.
- *Training and Education:* Proper training for personnel involved in air pollution measurement is essential to minimize human error. This training should cover instrument operation, calibration procedures, data recording, and analysis techniques. Ongoing education and certification programs can help ensure that staff stay up-to-date with the latest best practices and technological advancements.
- *Data Interpretation Guidelines:* Establishing clear guidelines for data interpretation can help mitigate the risks of misinterpretation. These guidelines should emphasize the importance of considering long-term trends, understanding local pollution sources, and accounting for uncertainty. In addition, involving experts in atmospheric science, statistics, and public health in the interpretation process can provide a more comprehensive understanding of the data.
- *Use of Advanced Technologies:* Advances in technology, such as the integration of artificial intelligence (AI) and machine learning (ML) in data analysis, can enhance the accuracy and reliability of air pollution measurements (Liu et al., 2022). AI and ML can help identify patterns in complex data sets, predict pollution events, and optimize measurement strategies. Additionally, deploying sensors in networks, combined with real-time data processing and cloud-based platforms, allows for more robust and scalable monitoring solutions (ISO/IEC, 2017; Spinelle, 2015; U.S. EPA, 2017; European Commission, 2010; ISO, 2015; Artiola et al., 2004; JCGM, 2008; Liu et al., 2022; Ma et al., 2020).

5 Health Impacts of Air Pollution

5.1 Global Burden of Disease and Mortality Trends

The impact of air pollution on human health has been extensively studied, revealing significant correlations with increased mortality and a wide range of diseases. Air pollution, particularly from fine particulate matter (PM) and ozone (O_3), has been identified among the major risk factors contributing to the global burden of disease. However, those are not the

only air pollutants; nitrogen oxides, sulfur dioxide, and carbon monoxide among others are also of concern (Chen et al., 2022; Ku et al., 2017; Nguyen et al., 2022; Shcheklein & Dubinin, 2020). The sources of PM are diverse, ranging from vehicle emissions and industrial processes to power plants and natural events like wildfires and dust storms. Particulate matter is a leading contributor to global disease burden, significantly affecting morbidity and mortality rates.

According to the Global Burden of Disease Study 2015, ambient $PM_{2.5}$ was the fifth-ranking mortality risk factor globally in 2015, causing approximately 4.2 million deaths and 103.1 million disability-adjusted life years (DALYs) (Cohen et al., 2017). Exposure to ozone was associated with 254,000 deaths globally and a loss of 4.1 million DALYs in 2015, predominantly affecting those with chronic obstructive pulmonary disease (COPD) (Cohen et al., 2017). The analysis of global, regional, and country-level data from 1990 to 2015 shows a disturbing trend of increasing deaths attributable to air pollution, particularly in low-income and middle-income countries. The highest burdens were observed in East and South Asia, accounting for 59 % of the total deaths related to ambient $PM_{2.5}$ exposure in 2015 (Cohen et al., 2017; Lelieveld et al., 2015).

Despite reductions in air pollution levels in some high-income countries, global mortality rates associated with $PM_{2.5}$ have continued to rise due to increasing pollution in densely populated and rapidly industrializing regions. Models estimating premature deaths assuming the same present scenario indicate that the contribution of air pollution may double by 2050 (Lelieveld et al., 2015). The detrimental effects of air pollution extend beyond mortality to significantly impact overall health; it may shorten life expectancy or reduce years of healthy life. Overall health status and other factors may modify the effect of air pollution on health. Many other non-communicable diseases (Campbell-Lendrum & Prüss-Ustün, 2019) have been also related to air pollution such as immune system diseases (Glencross et al., 2020), cardiovascular damage (Al-Kindi et al., 2020), inflammation (Arias-Pérez et al., 2020), neurological and cognitive decline (Schraufnagel et al., 2019), bone health decline (Prada et al., 2020), pulmonary diseases (Ko & Kyung, 2022) and autoimmune diseases (Zhao et al., 2019).

5.2 Specific Physiological Effects of Air Contaminants

Particulate Matter PM_{25} and PM_{10}

Particulate matter is a mixture of tiny solid particles and liquid droplets in the air, categorized by size. $PM_{2.5}$ is particularly harmful as it can penetrate deeply into the lungs and bloodstream, causing significant cardiovascular, respiratory, and systemic health issues (Garcia et al., 2023), with notable variations in relative risk based on age (Cohen et al., 2017). In low-income countries, indoor air pollution due to the burning of solid fuels is the major source of $PM_{2.5}$ and it is a major health concern. In more industrial countries the most important emissions are generated by traffic and industries, whereas other regions of the world have agricultural emissions as the major source of particles (Lelieveld et al., 2015). The inhalation of PM can have profound health effects, impacting various bodily systems. Respiratory infections are one of the primary concerns, as PM can irritate the airways (Gavett & Koren, 2012; Xing et al., 2016; Xu et al., 2020). The toxicity of particles is considered concentration-dependent, but not source-dependent, as there is no evidence supporting source-specific risks for burden estimation, but this issue needs to be deeply investigated.

Increasing levels of fine particulate air pollution are associated with a significant rise in cardiopulmonary mortality. Specifically, each 10 μg/m³ elevation in long-term average $PM_{2.5}$ concentrations correspond to an approximate 6 % increased risk of cardiopulmonary mortality, 8 % of lung cancer and 4 % of risk of all causes (Pope III et al., 2002). Heart disease is another major health issue linked to PM exposure. The fine particles can cause inflammation and increase blood pressure, thereby damaging the heart and blood vessels. This can lead to an increased risk of heart attacks, strokes, and other cardiovascular problems (Brook et al., 2010; Fang et al., 2010; Liang et al., 2020; Nelin et al., 2012; Thompson, 2018). Exposure to PM is an established cardiovascular risk factor and reducing exposure would lower the risks (Brook et al., 2010). Additionally, long-term exposure to PM is a significant risk factor for lung cancer (Ciabattini et al., 2021; Cui et al., 2014; Lippi & Mattiuzzi, 2020; Thompson, 2018). The particles can damage the cells lining the lungs, leading to mutations that may result in cancer. Beyond respiratory and cardiovascular problems, PM exposure has been associated with a range of other health issues. These include diabetes (Lao et al., 2019; Liu et al., 2016; Thompson, 2018; Zhou et al., 2022), cognitive decline (Aretz et al., 2021; Ranft et al., 2009; Shehab & Pope, 2019), and premature death (Burnett et al., 2018; Li et al., 2018).

Nitrogen Oxides (NO_x)

Nitrogen oxides (NO_x), including nitrogen dioxide (NO_2) and nitric oxide (NO), are produced primarily through high-temperature combustion processes in vehicle engines and power plants. NO_x are reddish-brown gases that significantly contribute to the formation of ground-level ozone and fine PM, both of which have detrimental health effects. Exposure to NO_x can irritate the respiratory system, leading to various health issues (Shcheklein & Dubinin, 2020). One of the most immediate effects of NO_2 exposure is respiratory irritation (Chen et al., 2022; Jiang et al., 2019a). The gas irritates the tissues lining the nose, throat, and lungs, causing symptoms like coughing, wheezing, shortness of breath, and chest tightness. This irritation can exacerbate pre-existing respiratory conditions, making them more severe and harder to manage. For individuals with asthma, NO_2 is particularly problematic as it can trigger asthma attacks and worsen overall symptoms, leading to increased difficulty in controlling the condition (Ghosh et al., 2012; Kjaer & Rasmussen, 1996).

Moreover, exposure to NO_2 can weaken the body's defense mechanisms against respiratory infections, increasing susceptibility to illnesses such as bronchitis and pneumonia (Ghosh et al., 2012; Lee et al., 2013; Pershagen et al., 1995). The compromised immune response makes it easier for pathogens to infect the respiratory tract, leading to more frequent and severe infections. A longitudinal study reported an association between NO_2 exposure and respiratory illness, finding it more robust for bronchitis than for upper airway inflammation, with increased risk between birth and 2 years (Ghosh et al., 2012). Long-term exposure to NO_2 can also result in significant lung function impairment (Gaffin et al., 2018; Jiang et al., 2019b; Rao et al., 1992). Continuous inhalation of this gas can damage lung tissues, reducing overall lung function and making breathing more difficult. This reduction in lung capacity not only affects daily activities but also decreases the ability to exercise, impacting overall health and quality of life (Eckhardt & Wu, 2021).

Sulfur Dioxide (SO_2)

Sulfur dioxide (SO_2) is a colourless gas with a pungent odor, primarily produced by volcanic eruptions and industrial processes such as burning Sulphur-containing fossil fuels like coal

and oil. Despite significant regulatory efforts to reduce SO_2 levels, exposure to this gas continues to pose health risks, particularly respiratory irritation. SO_2 in the atmosphere can react to form fine sulfate particles, which contribute to $PM_{2.5}$ pollution and exacerbate respiratory problems (Ku et al., 2017). Exposure to SO_2 can irritate the tissues lining the nose, throat, and lungs, leading to symptoms such as coughing, wheezing, shortness of breath, chest tightness, and a burning sensation in the upper airways. These symptoms can be particularly severe for individuals with pre-existing respiratory conditions, such as asthma. In such cases, SO_2 can worsen asthma symptoms, triggering asthma attacks and making it more difficult to manage the condition effectively (Chen et al., 2012; Chen et al., 2022; Linn et al., 1987), even at short peak exposures (Johns et al., 2011). In addition to immediate respiratory irritation, SO_2 exposure can increase susceptibility to respiratory infections by weakening defense mechanisms.

Ground-Level Ozone (O_3)

Ozone is a gas molecule composed of three oxygen atoms and is a major component of ground-level smog. Ground-level O_3 is formed through chemical reactions between sunlight and pollutants such as NO_x and volatile organic compounds (VOC_s) emitted from vehicles and power plants (Nguyen et al., 2022). While O_3 in the stratosphere plays a crucial role in protecting the Earth from harmful ultraviolet radiation, ground-level O_3 poses significant health risks. Exposure to ground-level O_3 can irritate the respiratory system, leading to a variety of health problems (Chen et al., 2022). Ozone exposure irritates the tissues lining the lungs, akin to a sunburn on the skin. This irritation can cause symptoms such as coughing, wheezing, chest tightness, and shortness of breath.

These effects are particularly pronounced in individuals with asthma, as O_3 can significantly worsen asthma symptoms, trigger asthma attacks, increase the need for medication, and result in more frequent hospital visits (Lin et al., 2008). Male and older asthma patients may be more vulnerable to O_3 air pollution, especially in the warm season (Fang et al., 2022). Furthermore, exposure to O_3 can reduce lung function, making it more difficult to breathe deeply and exercise. This reduction in lung function can be temporary, but with long-term exposure, it may become permanent, impacting overall respiratory health. In addition to these direct respiratory effects, O_3 weakens the body's defense system against respiratory infections, increasing susceptibility to illnesses like bronchitis and pneumonia (Backus et al., 2010; Dimakopoulou et al., 2020).

Carbon Monoxide (CO)

Carbon monoxide (CO) is a colorless, odorless gas produced by the incomplete combustion of fuels such as gasoline, wood, and coal. Its undetectable nature makes it particularly dangerous because it cannot be detected by human senses. CO interferes with the oxygen-carrying capacity of red blood cells, leading to a range of health effects that can escalate rapidly. Initially, exposure to CO often causes mild headaches, which can easily be mistaken for common headaches, delaying the recognition of CO poisoning (Chen et al., 2022). As CO levels increase in the blood, symptoms such as dizziness, nausea, and vomiting become more pronounced. These symptoms can be particularly hazardous as they may lead to falls or impair the ability to escape from the source of the CO.

Additionally, CO poisoning can cause extreme fatigue and weakness, further impairing judgment and coordination, which makes it difficult for individuals to leave a contaminated

environment (Roderique et al., 2015). At higher concentrations, CO exposure can lead to confusion, disorientation, and even hallucinations. This mental impairment can be life-threatening as it prevents individuals from seeking help or understanding the need to evacuate. In severe cases, the effects of CO poisoning escalate to loss of consciousness and even death due to the deprivation of oxygen in vital organs such as the brain and heart (Abdel salam et al., 2021). The health risks associated with CO underscore the importance of preventing CO exposure through proper ventilation and the use of CO detectors. Awareness and early detection are crucial in preventing the harmful and potentially fatal effects of this silent and invisible gas.

5.3 Vulnerable Populations and Demographic Aging in Europe

Air pollution is a well-documented cause of a wide range of health problems, particularly in densely populated regions of Europe. The World Health Organization (WHO, 2010) reported that environmental issues are also strongly connected to health status and social deprivation. The situation escalated to the levels where "air pollution has overtaken poor sanitation and a lack of drinking water to become the main environmental cause of premature death" (Kelly & Fussell, 2015). Therefore, European Member States are required to take continuous measurements of air emissions (WHO, 2005). As an authoritative source of scientific evidence on cancer-causing substances and exposures, the International Agency for Research on Cancer has classified air pollution in general, as well as PM as a major component of air pollution mixtures, as carcinogenic to humans (IARC, 2013). A growing number of environmental and epidemiology studies have demonstrated that short- (over a few hours or days) and long-term (over months or years) exposure to high concentration of airborne PM are closely related to the incidence of acute and chronic diseases and mortality, mainly related to cardiovascular and respiratory system (Cohen et al., 2006; WHO, 2013; Lelieveld et al., 2015; Yin et al., 2017; GBD, 2018). According to results of the Global Burden Disease Study 2017 (GBD, 2018), 38.44 per 100,000 populations all causes of deaths were attributable to ambient PM pollution, and PM identified as one of eight global death risk factors. In 2020, the European Environment Agency reported that PM alone accounted for around 399,000 of premature deaths in European countries (EEA, 2020).

Many epidemiological studies have shown that susceptible populations like those with prior cardiovascular or pulmonary disease and individuals with obesity and diabetes, are in greater health risk from elevated $PM_{2.5}$ pollutions, including the elderly (>65 years of age) with such comorbidity (Pope et al., 2006; Villeneuve et al., 2012; Burnett et al., 2018). Ageing is a global phenomenon, since every country in the world is experiencing growth in the share of older people in total population. According to the global United Nations study (UN, 2019), there were 703 million persons aged ≥65\ge 65≥65 years in 2019. According to the same source, the number of elderly is projected to 1.5 billion in 2050, so that "one in six people in the world will be aged 65 years or over". This demographic structure is expected to put pressure on governments and public expenditures for elderly which require not only long-term medical care but assistance with a number of daily tasks. Therefore, it is obvious that ageing will pose an increasing challenge to the sustainability of public finances in the EU-27.

Significant social inequalities in environmental exposures exist between and within countries (WHO, 2010; Pisoni et al., 2021). It is known that air quality is often worse in locations where socioeconomically disadvantaged residents live, so it is evident that they are disproportionately more exposed to environmental risk factors (US EPA, 2010). Some population groups are more exposed to the $PM_{2.5}$ air pollution, such as citizens living in the

sparse city microenvironments with higher pollution exposures (WHO, 2010; Rajagopalan et al., 2020), and/or some of them are more susceptible like elderly, which mostly have pre-existing health conditions (Chau et al., 2020). Ageing is an intrinsic process of progressive decline of the body's function that leads to increased sensitivity and vulnerability of elderly. Facing the same level of exposure to $PM_{2.5}$, elderly adults are more susceptible than the general population (Hooper et al., 2018). As they are at higher risk for adverse health effects, the exposure to the $PM_{2.5}$ air pollution may even be fatal, due to comorbidity (Simoni et al., 2014).

Many studies reported morbidity and mortality of the elderly associated to the $PM_{2.5}$air pollution exposure. It is known that $PM_{2.5}$ exerts a great influence on the cardiovascular and respiratory system in all population groups, and contributes to morbidity, hospital admissions and premature deaths (Wong et al., 2002; Gent et al., 2009; Dominici et al., 2006). Dominici et al. (2006) reported that long-term exposure to elevated concentrations of $PM_{2.5}$ has been related to the significant incidence of COPD and asthma. Air pollution-related carcinogenesis, which mostly occurred in the elderly, has also been studied as of particular interest to the public health, but remains to be elucidated. Still, extensive evidence from numerous studies provides arguments of positive correlation between elevated concentrations of airborne $PM_{2.5}$ and incidence and mortality of lung, tracheal or bronchus cancer (Pope et al., 2002; Ding et al., 2014; Cao et al., 2018; Turner et al., 2020).

Research published by Lelieveld et al. (2019) demonstrates that air pollution, particularly $PM_{2.5}$, contributes to approximately 800,000 premature deaths annually across Europe, underlining the severe public health burden of pollution. Long-term exposure to fine particulate matter is associated with increased incidences of heart attacks, strokes, COPD, and lung cancer (Raaschou-Nielsen et al., 2013; Beelen et al., 2014). The health impacts are not uniformly distributed, as studies indicate substantial geographical and socio-economic disparities. For example, research by Forouzanfar et al. (2016) demonstrates that Eastern Europe suffers from higher mortality rates due to air pollution compared to Western European countries, largely due to the slower implementation of stringent pollution control measures. Moreover, children and the elderly are disproportionately affected, with children exposed to air pollution exhibiting increased risks of asthma, bronchitis, and developmental issues (Brunekreef & Holgate, 2002; Gehring et al., 2013; Sunyer et al., 2015). The WHO (2024) further confirms that air pollution exacerbates pre-existing health conditions, particularly among vulnerable populations, amplifying public health disparities across Europe.

6 Environmental and Ecological Consequences

6.1 Acidification of Soils and Aquatic Systems

In addition to its impacts on human health, air pollution poses a significant threat to the environment. Pollutants such as sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds (VOC_s) can cause damage to ecosystems through acidification, eutrophication, and ozone formation. Acid deposition, primarily driven by sulfur and nitrogen compounds, has been linked to soil degradation and water acidification, particularly in sensitive ecosystems like the Scandinavian boreal forests (De Vries et al., 2015). Studies by Skjelkvåle et al. (2001) and Fenn et al. (2003) have documented the long-term effects of acid rain on European ecosystems, where terrestrial and aquatic biodiversity has been significantly affected. The loss of fish populations in acidified lakes and rivers in Sweden and Norway is a direct consequence of these pollutants, as reported by Henriksen et al. (1992).

Acid rain, resulting from the deposition of sulfur and nitrogen compounds, has been a major environmental concern in Europe for decades. Acidification of soils and water bodies can lead to the loss of biodiversity, as many plant and aquatic species are sensitive to changes in pH levels. Although emissions of SO_2 have decreased significantly in Europe since the 1980s, acidification remains a problem in certain regions, particularly in areas with low buffering capacity, such as the Scandinavian countries and parts of Eastern Europe (Sutton et al., 2011).

Eutrophication, the process by which excessive nutrients, particularly nitrogen compounds, accumulate in water bodies, leading to algal blooms and oxygen depletion, is another critical consequence of air pollution. Nitrogen oxides and ammonia emitted from agriculture, transport, and industry contribute to the nitrogen load in aquatic ecosystems, causing harmful effects on biodiversity and water quality. Research by Dise et al. (2011) showed that nitrogen deposition has led to the decline of plant species adapted to low-nutrient environments, resulting in the loss of biodiversity in grasslands and heathlands across Europe. The study also emphasized the role of nitrogen pollution in disrupting the balance of nutrient cycles, leading to long-term degradation of sensitive ecosystems such as peatlands and wetlands (Dise et al., 2011).

6.2 Impacts on Agricultural Productivity and Forestry

Ground-level ozone, a secondary pollutant formed by the reaction of VOC_s and NO_x in the presence of sunlight, is harmful to vegetation and crops. Ozone exposure reduces photosynthesis, damages leaf structure, and impairs plant growth, leading to reduced agricultural yields and forest productivity. In Europe, ozone pollution is a significant concern for both food security and ecosystem health. A study conducted by Mills et al. (2011, 2018) estimated that ozone pollution causes crop yield losses worth billions of euros each year in Europe. The most affected crops include wheat, barley, and potatoes, which are highly sensitive to ozone damage. Additionally, forest ecosystems are at risk, with ozone exposure reducing tree growth and increasing vulnerability to pests and diseases.

Moreover, ozone pollution contributes to the reduction of crop yields and forest productivity, with Mills et al. (2011) estimating that O_3 induced yield losses for staple crops like wheat, barley, and potatoes could reduce agricultural productivity by up to 10 % in parts of Europe. A study by Bobbink et al. (2010) found that nitrogen deposition can lead to the degradation of semi-natural grasslands, which are important for livestock grazing and biodiversity conservation. The loss of these ecosystems has economic implications for farmers who rely on them for grazing and hay production.

7 Economic Implications and Theoretical Frameworks

7.1 Direct and Indirect Economic Costs

Calculating the health costs has been the subject of a number of studies over the last 30 years. Intrinsic value of life and health, and the monetary equivalent of the public health expenditures are quite sufficient arguments to reduce the impacts of the $PM_{2.5}$ air pollution. By reducing $PM_{2.5}$ emissions, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. At the same time, public health policy tends to invest funds in medical treatments that certainly have an impact on the national economy, and vice versa. In addition, air pollution also has considerable economic and social implications on household, hospital and public budgets due

to increase of medical costs of morbidity and mortality and reduced working productivity (WHO, 2015).

From an economic perspective, the costs associated with air pollution are staggering (Holland et al., 2015; Amann et al., 2013). The economic consequences of air pollution in Europe are substantial, with costs arising from healthcare expenses, loss of productivity, and damage to ecosystems and infrastructure. Air pollution-related illnesses lead to increased healthcare expenditures and lost workdays, while damage to agriculture, forests, and water bodies has long-term economic implications. The health impacts of air pollution place a significant burden on healthcare systems, borne disproportionately by countries with higher pollution levels and weaker healthcare infrastructure, such as those in Eastern and Southern Europe.

A report by the OECD (2014, 2016, 2019) highlighted that the economic costs of air pollution-related health impacts, including hospital admissions, medication, and outpatient care, represent a significant portion of national healthcare budgets. Additionally, lost workdays due to pollution-induced illnesses contribute to reduced economic productivity, particularly in urban and industrial areas where pollution levels are highest. Air pollution, particularly from sulfur dioxide and nitrogen oxides, can cause damage to buildings and infrastructure through the process of acid deposition. Acid rain accelerates the corrosion of metals, stone, and concrete, leading to higher maintenance and repair costs for historic buildings, monuments, and infrastructure. In Europe, the economic costs of acid rain-related damage to buildings are estimated to be in the billions of euros annually (European Commission, 2017). A study by Tidblad et al. (2010) found that the rate of corrosion of building materials, such as limestone and steel, is strongly correlated with the concentration of SO_2 in the atmosphere. Although SO_2 emissions have decreased significantly in Europe, many historic buildings and cultural heritage sites remain vulnerable to pollution-induced deterioration, particularly in urban areas with high traffic emissions.

7.2 The Environmental Kuznets Curve and Decoupling Paradigms

It is evident that the economic development and pollution rate are closely related, although there is no clear consensus on the nature of that relationship. In mathematical terms, this relationship (usually referred to as Environmental Kuznets Curve) can be divided into following categories:

- *An inverted U-shaped relationship:* Introduced in the context of environmental degradation with three different stages: scale effect where the environment is increasingly polluted due to increased exploitation of natural resources; composition effect that emphasizes cleaner activities in production where consequently pollution rate stagnates in spite of economic growth; and techniques effect where, due to increased economic development, obsolete technologies are replaced by cleaner ones and consequently pollution rate decreases (Ekins, 1997; Kiliç & Balan, 2018).
- *A monotonically increasing relationship:* Where there is a clear positive feedback between GDP per capita and environmental impact. In other words, there is "an increasing rate of environmental degradation per unit of income as countries become richer" (Bagliani et al., 2008).
- *N-shaped relationship:* Basically represents prolonged inverted U-shaped relationship where beyond certain income level negative pressure on the environment increases again (Allard et al., 2018).

As Grossman and Krueger (1994) stated, GDP growth is associated with deteriorating of environmental quality. However, after reaching critical level of income, economic growth tends to alleviate environmental issues (Grossman & Krueger, 1991). In last few decades, there is lot of evidences that further economic development and transformation based on knowledge, innovations, new technologies and environmental governance could be driving forces for improvement of the environmental standards and quality (Holtz-Eakin & Selden, 1992; Shao et al., 2016; Kogan et al., 2017; Feng et al., 2019; Huang et al., 2019; Li et al., 2020).

Recently available data of European Environment Agency suggest that over the last 50 years the environmental policies of EU-27 countries have been able to curb air pollution (EEA, 2020). According to the same source, the EU-27 has failed to reduce $PM_{2.5}$ air pollution to the extent that it does not significantly affect human health. Individually oriented environmental policies implemented to reduce $PM_{2.5}$ emissions from road transport, domestic heating, industry and agriculture have proved insufficient. Recently, EU-27 responded with paradigm of sustainability transition based on decoupling of harmful environmental pollution from economic growth. This ambition has been immersed in new policies and initiatives, such as European Green Deal, with the key message that the economy does not have to be in conflict with the environment.

8 Policy Responses, European Initiatives, and Post-COVID Perspectives

8.1 Transboundary Agreements and Regulatory Frameworks

These findings underscore the critical need for comprehensive air quality management and policy interventions aimed at reducing emissions from major sources such as coal combustion and vehicular traffic. Effective policy measures could lead to significant health benefits and reductions in the disease burden attributable to air pollution. The substantial public health benefits observed in countries with aggressive air quality management programs, such as the United States, illustrate the potential gains from such interventions (Cohen et al., 2017). The transboundary nature of air pollution complicates mitigation efforts, as pollutants such as PM and O_3 can travel long distances, affecting regions far from their original source (Wilson & Suh, 1997; Li et al., 2017). Their half-life is up to several weeks with travel distance more than 1,000 kilometers (Wilson & Suh, 1997). This has prompted coordinated efforts through the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), which has facilitated significant reductions in sulfur and nitrogen emissions across Europe (UNECE, 1979; Höglund-Isaksson et al., 2017). Additionally, urban air pollution has intensified due to traffic emissions, with NO_x and black carbon concentrations frequently exceeding EU air quality standards in major cities (Kiesewetter et al., 2015).

Due to the public health implications, the World Health Organization (WHO, 2005) and the EU Ambient Air Quality Directive set the standards of airborne pollutants and guidance on threshold limits that pose health risks. Provisions of the global (UNECE, 1979; WHO, 2005) and European environmental policy related with monitoring and control of ambient air pollution is a highly cost-effective intervention in reducing $PM_{2.5}$ related morbidity and mortality. European Green Deal Policies aim to promote the implementation of actions that can significantly impact air quality (European Commission, 2024; KPMG, 2024). The European Commission does play a significant role in ensuring that EU Member States adopt actions aligned with the European Green Deal. This enforcement is primarily achieved through the European Climate Law, which legally binds Member States to achieve climate

neutrality by 2050 and sets a greenhouse gas emissions reduction target of at least 55% by 2030 compared to 1990 levels (European Commission, 2024). The European Climate Law was established to provide a framework for achieving the Green Deal's objectives. It mandates regular assessments and adjustments to national policies and measures to ensure they are on track to meet these targets. Moreover, the law includes mechanisms for monitoring and reporting progress, enabling the European Commission to take corrective action if necessary.

The World Health Organization (WHO) does not have the authority to enforce its guidelines on air quality or compel governments to implement specific actions. Instead, the WHO provides scientifically based recommendations and guidelines intended to help countries improve air quality and protect public health. The WHO encourages governments to adopt these guidelines to mitigate the health risks associated with poor air quality, but the implementation of these measures is ultimately at the discretion of each country's government. WHO published in 2021 the last version of its WHO global air quality guidelines (WHO, 2021) recommending several key measures to enhance air quality and protect public health from pollution's harmful effects. These measures are informed by scientific evidence and involve various sectors (WHO, 2021):

- *Regulatory Actions:* Governments should enforce national air quality standards that align with WHO guidelines, covering pollutants such as $PM_{2.5}$, P_{M10}, nitrogen dioxide, sulfur dioxide, and ozone. Regular updates are needed to reflect new scientific findings.
- *Emission Reductions:* Efforts should focus on minimizing or eliminating polluting activities across transportation, industry, agriculture, and residential heating.
- *Urban Planning:* Incorporate air quality considerations into urban planning to reduce exposure by optimizing traffic flow, increasing green spaces, and appropriate location of industrial areas. Encourage shorter travel distances and use of public transportation (reduce private) and promote walking and cycling in cities.
- *Public Awareness:* Conduct campaigns to inform the public about the health risks of air pollution and encourage behaviors that reduce emissions and personal exposure, such as energy-efficient practices and reducing the use of high-emission appliances.
- *Monitoring and Data:* Establish extensive air quality monitoring networks and ensure the data is publicly accessible to inform policy decisions. Use high-resolution models and citizen science initiatives to supplement governmental monitoring.
- *Health Risk Assessments:* Perform assessments to estimate the health impact of air pollution and understand the benefits of air quality improvements, guiding policy decisions.
- *International Collaboration:* Engage in global initiatives to share knowledge, build capacity, and coordinate actions to address transboundary air pollution.
- *Research and Development:* Support research into the health effects of air pollution, new monitoring technologies, and innovative mitigation strategies.

8.2 Empirical Lessons from the COVID-19 Pandemic (2020-2024)

On the other hand, the COVID crisis highlighted the need for a common European response to public health and economic challenges. As a result of lock-down measures, the concentrations of $PM_{2.5}$ emissions have decreased significantly (EEA, 2020), pointing out that radical changes have yet to be made in the EU-27 economy in terms of reducing air pollution. The research done during and after COVID-19, in the period from 2020 to 2024, has seen a significant reevaluation of the consequences of air pollution in Europe, particularly as new

scientific data has emerged in light of the COVID-19 pandemic, advancements in monitoring technology, and evolving policy frameworks. Recent studies have continued to highlight the far-reaching impacts of air pollution on human health, environmental integrity, and economic sustainability.

According to the European Environment Agency's (EEA) 2023 report, air pollution remains the leading environmental risk factor for premature mortality in Europe, with fine particulate matter ($PM_{2.5}$ nitrogen dioxide (NO_2), and ground-level ozone (O_3) contributing to more than 380,000 premature deaths annually within the European Union (EEA, 2023). This period has also brought attention to the exacerbating effects of air pollution on respiratory diseases, particularly in the context of the COVID-19 pandemic. Research by Travaglio et al. (2021) identified a positive correlation between long-term exposure to $PM_{2.5}$ and higher mortality rates from COVID-19, underscoring the interaction between pollution and vulnerability to viral infections (Ciencewicki & Jaspers, 2007).

In terms of health impacts, recent meta-analyses have strengthened the link between air pollution and cardiovascular and respiratory diseases. A 2022 study by Schraufnagel et al. emphasized that prolonged exposure to air pollution exacerbates chronic conditions such as asthma, COPD, and ischemic heart disease, particularly in urban populations. Furthermore, a study by Vicedo-Cabrera et al. (2023) found that short-term spikes in ozone levels during heatwaves significantly increase hospital admissions for respiratory diseases, highlighting the compounded risks posed by climate change and air pollution. In children, prenatal and early-life exposure to air pollution has been linked to developmental issues, including cognitive impairment and lower lung function (Vrijheid et al., 2021). These findings align with the WHO's (2021, 2024) revised air quality guidelines, which lower the recommended exposure thresholds for $PM_{2.5}$ and NO_2 to further reduce public health risks.

Environmentally, the consequences of air pollution continue to affect biodiversity and ecosystem services. Amann et al. (2020) demonstrate that nitrogen deposition remains a significant threat to biodiversity in Europe, with sensitive habitats such as heathlands and alpine ecosystems particularly vulnerable. Nitrogen oxides and ammonia emissions from agriculture and transport contribute to eutrophication, which disrupts plant diversity and alters species composition in terrestrial and aquatic ecosystems (Sutton et al., 2020). Acidification, though reduced since the 1990s, remains a concern in certain regions, particularly in northern Europe. According to an assessment by De Vries et al. (2022), although sulfur deposition has declined substantially due to regulatory efforts, nitrogen-driven acidification continues to degrade soil quality and water bodies, adversely affecting forest growth and freshwater biodiversity. The agricultural sector has also been impacted by air pollution, with ozone exposure reducing crop yields across Europe. According to a study by Wilkinson et al. (2021), ground-level ozone caused yield losses of up to 5-10 % for key European crops such as wheat, barley, and potatoes between 2020 and 2022. These losses are projected to increase as climate change exacerbates ozone formation, threatening food security and economic stability. The European Commission´s 2021 Farm to Fork Strategy has emphasized the need to address agricultural emissions, particularly ammonia, to reduce air pollution and its associated impacts on crop productivity (EEA, 2022).

A study by Qu et al. (2021) found that lockdowns during the COVID-19 pandemic provided temporary relief from traffic-related pollution, but levels quickly rebounded as restrictions were lifted, highlighting the resilience of underlying pollution sources. Urban green spaces have been shown to mitigate air pollution's impacts by absorbing particulate matter and

providing health benefits to city residents (Lai et al., 2021), but their effectiveness is limited by the scale of emissions and urban sprawl.

8.3 Integrated Climate-Air Quality Governance

Policy responses during this period have been mixed. The EU's Green Deal and Zero Pollution Action Plan aim to achieve a 55 % reduction in greenhouse gas emissions and a 25% reduction in premature deaths due to air pollution by 2030 (European Commission, 2021). However, critics argue that the current pace of implementation is insufficient to meet these goals. For example, a report by Kiesewetter et al. (2022) suggests that while $PM_{2.5}$ levels have generally decreased, reductions in NO_2 and ammonia emissions are lagging, particularly in the transport and agricultural sectors. Recent legislative developments, such as the tightening of the National Emissions Ceilings Directive (NECD) and the proposed revision of the Ambient Air Quality Directive (AAQD), are steps towards addressing these challenges, but enforcement and compliance remain critical issues (Schucht et al., 2022).

Another significant development has been the focus on the intersection of air pollution and climate change. Research by Liu et al. (2023) shows that climate change is likely to exacerbate the frequency and severity of air pollution events, particularly through increased heatwave-induced ozone formation and changes in atmospheric circulation patterns. This period has seen growing calls for integrated air quality and climate policies to address these interconnected issues. Von Schneidemesser et al. (2015, 2021) argue that aligning air pollution control with climate mitigation efforts, particularly in sectors like energy and transport, is essential for achieving long-term reductions in pollution levels.

9 Aim of the Publication

The main aim of this publication was to examine public attitudes towards air quality and to explore how general environmental attitudes, perceptions of health and environmental risks, personal experience, awareness, and self-reported behaviour are interconnected in everyday life. The publication focuses not only on whether people perceive air pollution as a serious problem, but also on the extent to which this issue becomes personally relevant, whether they associate it with their place of residence and family, whether they have access to sufficient and useful information, and how they evaluate the roles of the media, education, public institutions, and legislative measures.

An important aspect of the publication was to identify the gap between general awareness and practical readiness to take action. Individuals may be aware that air pollution harms human health and the natural environment, yet they may not know the air quality conditions in their immediate surroundings, understand publicly available data, or know how to respond appropriately. The publication therefore examines the progression from general environmental attitudes through risk perception and perceived awareness to everyday behaviour and willingness to pay greater attention to air quality.

To achieve the main aim, two independent questionnaire surveys were conducted, examining the issue from complementary perspectives. Each study was analysed separately to preserve its conceptual framework, sample characteristics, and the meaning of individual questions. The combined findings provide a broader understanding of what the public knows about air quality, how it perceives the issue, and where opportunities exist to improve communication, education, and support for environmentally responsible behaviour.

Study 1

The aim of Study 1 was to examine how respondents perceive the environment and air quality, how their general environmental attitudes are associated with self-reported behaviour, and what roles personal experience, perceived awareness, and evaluations of the institutional environment play in shaping their views.

The survey first provides a broader picture of the importance respondents attach to the environment, which environmental problems they consider most serious, and the extent to which they personally attempt to contribute to positive change. General attitudes and everyday habits serve as a starting point for examining the central issue of air quality. They make it possible to assess whether higher self-reported environmental sensitivity is also associated with stronger perceptions of air pollution risks and more environmentally responsible behaviour.

Particular attention was paid to the distinction between generally acknowledging the harmful effects of air pollution and perceiving the problem as directly relevant to oneself, one's family, or one's place of residence. The survey therefore examined whether respondents consider air quality a serious issue, whether they are concerned about it, whether they recognise its health and environmental consequences, and whether they perceive changes in air quality in their local surroundings.

Another objective was to determine the extent to which respondents feel informed about air quality problems, their health effects, and their consequences for the natural environment. The survey also examined how respondents evaluate the attention devoted to air quality by the media and educational institutions, whether they have encountered solutions to

air quality problems, and how they perceive the adequacy of national and European legislation. Awareness was understood not merely as the amount of information received, but as the subjective perception of having sufficient knowledge to understand and navigate the issue.

Study 1 also examined whether attitudes, behaviour, risk perceptions, and awareness differ according to respondents' sociodemographic characteristics, particularly gender, age, educational attainment or student status, field of specialisation, type of settlement, and region. These comparisons were intended to identify groups with different attitudes towards air quality. However, the findings needed to be interpreted in light of the respondent selection procedure and the relatively small sizes of some subgroups.

Specific Objectives of Study 1

To achieve the main aim of Study 1, the following specific objectives were established:

- to assess respondents' environmental sensitivity and general environmental attitudes,
- to map self-reported environmental behaviour and selected everyday habits,
- to examine attitudes towards energy, mobility, and technological solutions,
- to assess the perceived severity of, concerns about, and personal impacts of air quality-related risks,
- to capture perceived changes in air quality in respondents' places of residence,
- to assess perceived awareness of air quality and its consequences,
- to evaluate the perceived roles of the media, education, legislation, and other institutional stakeholders,
- to examine relationships between environmental sensitivity, self-reported behaviour, risk perception, and perceived awareness,
- to identify differences among selected sociodemographic groups of respondents.

Study 1 was therefore intended not merely to describe individual responses, but primarily to demonstrate how different dimensions of people's relationship with air quality are interconnected. Its aim was to determine whether general environmental concern translates into personal concern about air quality, whether perceived threats are associated with everyday behaviour, and whether perceived awareness helps respondents better recognise the significance of the problem.

Research Assumptions of Study 1

Given the predominantly exploratory nature of the research, research assumptions were formulated instead of formal hypotheses. These assumptions were based on the thematic structure of the questionnaire and identified the main relationships to be examined in the collected data. Their purpose was not to establish causal effects, but to assess whether the expected associations and differences were reflected in respondents' answers.

RA1: ***Higher environmental sensitivity will be associated with more environmentally responsible self-reported behaviour.***

The first research assumption was based on the expectation that individuals who attach greater importance to the environment and perceive environmental problems more strongly would also be more likely to report efforts to behave in an environmentally responsible manner. This assumption therefore examined the relationship between environmental values and everyday actions.

RA2: ***Higher environmental sensitivity will be associated with stronger perceptions of air quality-related risks.***

The second research assumption linked general environmental attitudes with the central topic of the survey. It was expected that respondents with higher environmental sensitivity would be more likely to perceive air quality as a serious problem and to recognise its potential consequences for health, family, and the natural environment.

RA3: ***Respondents who perceive a deterioration in air quality in their place of residence will perceive air quality-related risks more strongly than those who do not perceive such deterioration.***

The third research assumption emphasised the importance of local experience. It was based on the idea that a problem becomes more urgent when individuals can associate it with the environment in which they live. Perceived deterioration in local air quality was therefore expected to be associated with greater concern, higher perceived severity, and stronger perceptions of personal and family consequences.

RA4: ***Higher perceived awareness will be associated with more favourable evaluations of media and educational attention to air quality and the adequacy of legislation.***

The fourth research assumption focused on the broader informational and institutional environment. It was expected that respondents who feel better informed would also evaluate the attention devoted to air quality by the media and educational institutions more favourably and would assess the adequacy of national and European legislation more positively. This assumption was intended to determine whether respondents perceive individual informational and institutional channels separately or form an overall evaluation of the environment in which air quality information is communicated and related problems are addressed.

The research assumptions established the framework for the analytical part of Study 1. Together, they enabled an assessment of how general attitudes are associated with personal perceptions of the problem, evaluations of efforts to address it, and self-reported everyday behaviour.

Study 2

The aim of Study 2 was to examine in greater detail how respondents understand air pollution, which pollution sources and pollutants they know, how they perceive its health, environmental, personal, and local consequences, and the extent to which they can use available information in everyday decision-making. The study also investigated awareness of air quality monitoring, the Air Quality Index (AQI), and measures implemented by Slovakia

and the European Union, as well as respondents' readiness to take specific actions to improve air quality.

While Study 1 provided a broader picture of environmental attitudes, risk perception, and perceived awareness, Study 2 focused more closely on the content of specific knowledge and the progression from general awareness to practical understanding. The key issue was therefore not only whether respondents knew that air pollution is harmful, but also whether they could identify specific pollutants, understood how air quality is monitored, knew where to find local air quality data, and were aware of possible solutions or individual actions.

Particular attention was paid to the distinction between self-reported understanding and practical knowledge. Individuals may feel that they understand the issue without necessarily knowing the significance of particulate matter, how air quality is measured, or where to find reliable and up-to-date information. Similarly, they may support improvements in air quality without knowing which measures are realistically feasible for their households. Study 2 therefore examined the entire informational and behavioural sequence, from understanding the problem through personal and local experiences to readiness to take action.

Study 2 also investigated whether knowledge, local experience, information-seeking behaviour, and willingness to act differed among selected sociodemographic groups. These differences were interpreted cautiously because some groups had relatively small sample sizes, and without a documented sampling frame and weighting procedures, the analysed sample cannot be regarded as representative of the Slovak population.

Specific Objectives of Study 2

To achieve the main aim of Study 2, the following specific objectives were established:

- to assess respondents' perceived understanding of air pollution and their knowledge of selected pollutants,
- to map respondents' perceptions of general and local sources of air pollution,
- to evaluate perceptions of the health, environmental, personal, and local consequences of air pollution,
- to identify health problems that respondents attribute to poor air quality and their perceptions of vulnerable population groups,
- to assess familiarity with air quality monitoring, measurement, and the Air Quality Index, including the use of local data,
- to examine awareness of measures implemented by Slovakia and the European Union and evaluations of their effectiveness,
- to assess respondents' general and specific readiness to change their behaviour,
- to identify information needs and preferred content for educational campaigns,
- to examine relationships between understanding, knowledge, the personal and local relevance of the problem, information-seeking behaviour, and willingness to act,
- to identify differences among selected sociodemographic groups of respondents.

Study 2 was therefore not intended merely to determine what respondents claim to know about air quality. Its purpose was to identify the points at which general awareness develops into practical knowledge and where the information-to-action process breaks down, whether in identifying pollutants, accessing local data, recognising public policy measures, or selecting a feasible individual action.

Research Assumptions of Study 2

Given the exploratory nature of the analysis, research assumptions were formulated instead of formal hypotheses. They were derived from the thematic structure of the questionnaire and aimed to examine the main relationships between understanding, knowledge, local experience, awareness, and readiness to act. Since these assumptions were formulated during the secondary analysis of previously collected data, their evaluation is predominantly exploratory and does not establish causal relationships.

RA1: ***Higher perceived understanding of air pollution will be associated with greater self-reported knowledge of specific pollutants.***

The first research assumption compared respondents' general sense of understanding with their more specific familiarity with the names of pollutants. Its purpose was to determine whether respondents' confidence in their understanding was supported by more detailed knowledge.

RA2: ***Stronger perceptions of health and environmental consequences will be associated with greater personal and local relevance of the problem.***

The second research assumption linked general recognition of the harmful effects of air pollution with the perception that the problem affects one's own life and place of residence. It examined whether awareness of the consequences was also associated with a stronger sense of personal relevance.

RA3: ***Greater personal and local relevance of the problem will be associated with a higher willingness to implement specific measures.***

The third research assumption was based on the expectation that a problem perceived as close and personally significant would be more likely to translate into readiness to take action.

RA4: ***Greater knowledge of possible individual actions will be associated with a higher willingness to implement specific measures.***

The fourth research assumption examined whether respondents who reported greater knowledge of specific actions to improve air quality also expressed a higher willingness to implement such measures.

RA5: ***Greater general willingness to act will be associated with increased attention to subsequent information about air quality.***

The fifth research assumption examined whether self-reported motivation was also associated with an intention to pay greater attention to the issue after receiving brief information about air quality.

10 Materials and Methods

10.1 Study 1

Study 1 was conducted as a quantitative questionnaire survey using a cross-sectional research design. It focused on public environmental attitudes, self-reported everyday behaviour, perceptions of risks associated with air pollution, and perceived awareness. The study also examined the personal and local impacts of the problem and evaluations of the roles of the media, education, and the legislative environment. The research was conducted within the VISIONAIR project and provided a foundation for the subsequent independent Study 2.

Characteristics of the Research Sample

The research sample consisted of 384 respondents. The distribution of respondents by gender, age group, current level of study, type of place of residence, and region of the Slovak Republic is presented in Table 1. Age groups were established retrospectively for the purpose of providing a clear descriptive overview of the sample.

Table 1. Sociodemographic Characteristics of Respondents – Study 1

Characteristic / Category	**N**	**%**
Gender		
Male	159	41.4
Female	225	58.6
Age		
18–24 years	145	37.8
25–34 years	128	33.3
35–44 years	53	13.8
45–54 years	36	9.4
55 years and over	22	5.7
Current Level of Study		
Bachelor’s degree studies	131	34.1
Master’s degree studies	117	30.5
Doctoral studies	13	3.4
Not currently studying	123	32.0
Type of Place of Residence		
Urban area	211	54.9
Suburban area	42	10.9
Rural area	131	34.1
Region of Residence		
Bratislava Region	75	19.5
Trnava Region	30	7.8
Nitra Region	39	10.2
Trenčín Region	36	9.4
Žilina Region	59	15.4
Banská Bystrica Region	53	13.8
Prešov Region	55	14.3
Košice Region	37	9.6

Source: Authors’ own elaboration based on research, 2024

Research Instrument and Data Collection Procedure

Data were collected between 20 February and 10 March 2024 by MN Force, s.r.o., an independent market research agency, using an established online respondent panel in Slovakia. The survey was accessible exclusively to registered panel members and was not publicly available. Eligible respondents were invited through notifications in their panel accounts and recruited according to predefined sampling quotas designed to approximate the sociodemographic structure of the Slovak population. The final research sample consisted of 384 respondents. This sample size corresponds to the conventional minimum required for estimating population proportions at a 95% confidence level and a ±5 percentage-point margin of error under simple random sampling assumptions. However, given the quota-based recruitment through an online panel, this theoretical margin of error should not be interpreted as a guaranteed level of sampling precision or representativeness. Participation was voluntary, and data were collected through a structured online questionnaire.

The research instrument was a structured questionnaire. The questions addressed the importance of environmental protection, environmental sensitivity, respondents' personal contributions to environmental protection, and the frequency of selected everyday activities. Additional items focused on attitudes towards electromobility, energy sources, and technological solutions to environmental problems. The main section of the questionnaire focused on air quality, the perceived severity of air pollution, concerns about its consequences, its impact on respondents and their families, and subjective assessments of changes in air quality in their places of residence.

A separate thematic section addressed respondents' awareness of air pollution and its consequences. The survey also examined the attention devoted to the issue by the media and educational institutions, as well as the perceived adequacy of national and European legislation. The questionnaire combined closed-ended questions, rating scales, and multiple-response items. Sociodemographic characteristics were used to describe the research sample and compare selected groups.

Data Processing and Analysis

Questionnaire responses were organised into a data matrix, with individual rows representing respondents and columns representing the variables under investigation. Before analysis, valid responses, missing data, and responses that were not applicable due to the questionnaire structure were distinguished. Absolute and relative frequencies were calculated for single-response questions, while individual response options were analysed separately for multiple-response questions. Percentages were calculated based on the number of respondents who provided valid answers to the respective questions.

For selected rating-scale questions, two approaches to percentage calculation were applied. The figures present the distribution of responses across the entire sample, including the "Do not know" category. In contrast, selected percentages reported in the text were calculated using only substantive responses, excluding the "Do not know" category from the denominator. This approach was adopted to distinguish respondents who expressed an opinion from those who were unable to assess the question. Consequently, percentages presented in the text may differ slightly from the corresponding proportions displayed in the figures.

To evaluate the research assumptions, selected questionnaire items were used to represent broader analytical dimensions. These included environmental sensitivity, self-reported environmental behaviour, perceived air quality-related risks, perceived awareness, and evaluations of the informational and institutional environment.

Environmental sensitivity was operationalised using items reflecting the importance attributed to environmental protection, perceived seriousness of environmental pollution, and concern about environmental issues. Self-reported environmental behaviour was assessed using indicators of respondents' declared efforts to contribute to environmental protection and the frequency of selected environmentally responsible activities.

Perceived air quality-related risks were represented by respondents' assessments of the seriousness of air pollution, concerns about its consequences, perceived personal and family impacts, and perceived health and environmental consequences. Perceived changes in local air quality were treated as a separate categorical variable when examining differences in risk perception.

Perceived awareness was assessed using respondents' evaluations of how sufficiently informed they felt about air quality problems, health effects, and environmental consequences. Evaluations of the informational and institutional environment were based on assessments of media and educational attention to air quality and the perceived adequacy of national and European legislation.

Where several questionnaire items were combined into a composite indicator, their response scales required consistent orientation so that higher values represented higher levels of the construct being examined. The precise aggregation procedure, treatment of missing and "Do not know" responses, and minimum number of valid items required to calculate each composite score must correspond to the procedures used in the statistical analysis.

The resulting indicators were used to evaluate associations between environmental sensitivity and self-reported behaviour (RA1), environmental sensitivity and risk perception (RA2), perceived local changes and risk perception (RA3), and perceived awareness and evaluations of the informational and institutional environment (RA4).

The analytical approach included descriptive statistics and the examination of relationships between variables. To evaluate the four research assumptions, associations were examined between environmental sensitivity, self-reported behaviour, risk perception, perceived awareness, and evaluations of the informational and institutional environment. For ordinal variables and composite indicators, relationships were assessed using correlation analysis, particularly Spearman's rank correlation coefficient. Group comparisons required consideration of the measurement scale and group sizes. The interpretation considered the direction and strength of associations alongside statistical significance, rather than relying solely on p-values.

10.2 Study 2

Study 2 was conducted as an independent quantitative cross-sectional questionnaire survey that built upon the thematic focus of the first survey. Its aim was to examine in greater detail respondents' understanding of air pollution, their knowledge of pollution sources and specific pollutants, their familiarity with air quality monitoring, and their readiness to implement practical measures. Particular attention was also paid to the distinction between perceived awareness and specific knowledge applicable to everyday life.

Characteristics of the Research Sample

The research sample consisted of 384 respondents. The distribution of respondents by gender, age group, current level of study, type of place of residence, and region of the Slovak Republic is presented in Table 2. Age groups were established retrospectively to provide a clear descriptive overview of the sample.

Table 2. Sociodemographic Characteristics of Respondents – Study 2

Characteristic / Category	**N**	**%**
Gender		
Male	218	56.8
Female	165	43.0
Prefer not to answer	1	0.3
Age		
18–24 years	106	27.6
25–34 years	102	26.6
35–44 years	85	22.1
45–54 years	53	13.8
55 years and over	38	9.9
Current Level of Study		
Bachelor's degree studies	78	20.3
Master's degree studies	172	44.8
Doctoral studies	15	3.9
Not currently studying	119	31.0
Type of Place of Residence		
Urban area	226	58.9
Suburban area	34	8.9
Rural area	124	32.3
Region of Residence		
Bratislava Region	71	18.5
Trnava Region	30	7.8
Nitra Region	35	9.1
Trenčín Region	41	10.7
Žilina Region	52	13.5
Banská Bystrica Region	50	13.0
Prešov Region	54	14.1
Košice Region	51	13.3

Source: Authors' own elaboration based on research, 2024

Research Instrument and Data Collection Procedure

Data collection for Study 2 was conducted between 20 February and 10 March 2024 by MN Force, s.r.o., an independent market research agency, using an established online respondent panel in Slovakia. The survey was accessible exclusively to registered panel members and was not publicly available. Eligible respondents were invited through notifications in their panel accounts and recruited according to predefined sampling quotas designed to approximate the sociodemographic structure of the Slovak population. The final research sample consisted of 384 respondents. Participation was voluntary, and data were collected through a structured online questionnaire. Although data collection took place during the same period as Study 1, the two studies were conducted independently, using separate samples of respondents.

The research instrument was a structured questionnaire comprising closed-ended questions, rating scales, multiple-response items, and selected open-ended questions. The introductory section examined perceived understanding of air pollution, knowledge of pollutants, and perceptions of the main pollution sources. Subsequent questions addressed

perceived health and environmental consequences, the personal and local relevance of the problem, health problems that respondents themselves attributed to poor air quality, and perceptions of vulnerable population groups.

A separate section focused on awareness of air quality monitoring and measurement, familiarity with the Air Quality Index, and the use of local data. Further questions examined awareness of measures implemented by Slovakia and the European Union, subjective assessments of their effectiveness, knowledge of practical actions, and respondents' willingness to take such actions. The final items addressed preferred content for information and educational campaigns and the intention to pay greater attention to air quality.

Data Processing and Analysis

Data were analysed using absolute and relative frequencies and graphical representations of responses. For questions allowing multiple responses, each selected category was evaluated separately; consequently, the percentages did not necessarily sum to 100%. "Do not know" responses were distinguished from substantive disagreement or neutral evaluations.

The statistical evaluation of Study 2 focused on five analytical relationships involving perceived understanding of air pollution, self-reported knowledge of specific pollutants, perceived consequences, personal and local relevance, knowledge of possible individual actions, willingness to implement specific measures, and intention to pay greater attention to information about air quality.

Perceived understanding of air pollution was assessed through respondents' self-evaluation of their general understanding of the issue. Knowledge of specific pollutants was represented by respondents' reported familiarity with the pollutants included in the questionnaire. This indicator reflected self-reported rather than objectively verified knowledge.

Perceived consequences were assessed using items addressing the health and environmental impacts of air pollution. Personal and local relevance was represented by respondents' assessments of the extent to which air pollution affected their own lives and constituted a problem in their place of residence.

Knowledge of possible individual actions was assessed through respondents' reported awareness of measures they could personally undertake to improve air quality. Willingness to implement specific measures was represented by their declared readiness to undertake the actions included in the questionnaire.

General willingness to act and intention to pay greater attention to subsequent information about air quality were examined as distinct dimensions. The latter represented a stated future intention rather than observed information-seeking behaviour.

Where multiple questionnaire items were combined into composite indicators, consistent coding was required to ensure that higher scores represented higher levels of the respective construct. The precise aggregation procedure, treatment of missing and "Do not know" responses, and minimum number of valid items required for calculating each indicator should be documented in accordance with the statistical calculations.

To evaluate the five research assumptions, Spearman's rank correlation coefficient (ρ) was used to assess associations between the selected ordinal variables and composite indicators. Statistical significance was assessed at the 0.05 level, with Holm's step-down correction applied to the five research-assumption tests to control the family-wise error rate associated with multiple testing.

Under Holm's procedure, the five unadjusted p-values were ordered from smallest to largest. They were then adjusted using sequential multiplication factors of 5, 4, 3, 2 and 1, with the resulting adjusted p-values constrained to be non-decreasing and capped at 1. Statistical significance was determined using the Holm-adjusted p-values.

Selected sociodemographic comparisons employed statistical procedures appropriate to the measurement scales and group sizes. The interpretation considered the direction, strength and substantive relevance of the observed associations alongside their statistical significance.

Both studies relied on self-assessments and self-reported responses. Perceived deterioration in air quality was not directly compared with monitoring-station data, and reported health problems did not constitute clinically verified consequences of exposure. Differences between the studies cannot be interpreted as changes in the attitudes of the same respondents or as demonstrated effects of project activities.

11 Results

11.1 Study 1: Environmental Attitudes, Behaviour and Perceptions of Air Quality in Slovakia

11.1.1 Environmental Sensitivity and General Environmental Attitudes

The first results section of Study 1 provides an initial picture of the place the environment occupies in respondents' values. It examines the importance they attach to it, how seriously they perceive pollution and which environmental problems they regard as most urgent. These general attitudes provide an important starting point for the subsequent sections of the survey, which gradually shift the focus towards everyday behaviour and air quality.

The results indicate high self-reported sensitivity to environmental issues. The environment was considered important or very important by 81.0% of respondents. Environmental pollution was regarded as a serious problem by 82.2%, and the same proportion reported being concerned about pollution. Approximately nine in ten respondents also perceived changes in weather over the past twenty years. Environmental issues were therefore not marginal within the sample but formed a widely accepted part of respondents' value orientations.

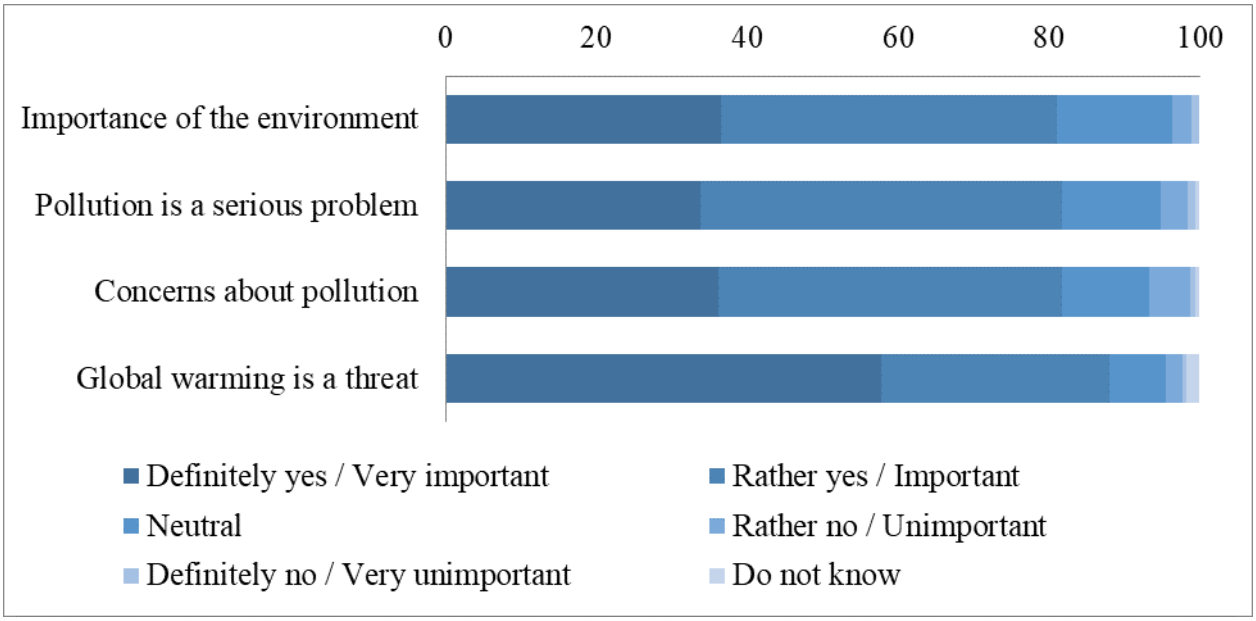


Figure 1. General Environmental Attitudes
Source: Authors' own elaboration based on research, 2024

However, attaching great importance to the environment does not necessarily mean that all environmental problems carry equal weight in the public's eyes. When asked to select the most serious problems from a list, respondents most frequently identified waste management. Air pollution was selected by 46.4% of respondents. As multiple answers were permitted, the percentages do not sum to 100% and cannot be interpreted as an objective ranking of environmental problems in Slovakia. Rather, they indicate which issues people most readily recall and perceive as closest to their everyday lives.

The prominence of waste may be related to its immediate visibility. People encounter it at home, when sorting waste and in public spaces. Air pollution is less straightforward in this respect. It is often not directly visible, and assessing it requires information about local sources, measurements or health consequences. Air quality was therefore neither rejected nor considered unimportant; rather, when competing with more visible everyday problems, it may not have been the first issue that came to respondents' minds.

The difference between the 81.0% of respondents who attached high importance to the environment and the 46.4% who ranked air pollution among the most serious problems is therefore not a contradiction. The former figure reflects a general relationship with the environment, whereas the latter indicates the position of air quality among several problems perceived simultaneously. An individual may consider air pollution serious but, when selecting issues spontaneously, prioritise a problem encountered more visibly or frequently.

The results also suggest that general attitudes are not entirely separate from personal actions. Respondents who considered the environment more important also tended to report environmentally responsible behaviour more frequently. These associations, however, do not demonstrate that a positive attitude automatically leads to specific action. They indicate only that values and self-reported behaviour were linked to some extent in respondents' answers.

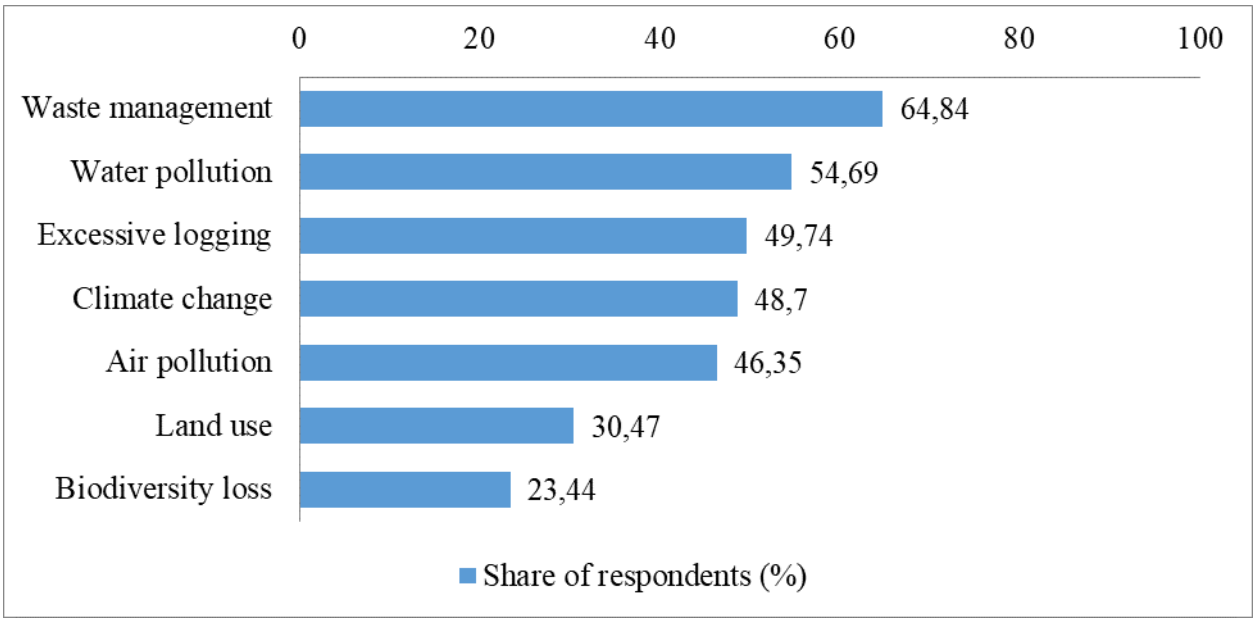


Figure 2. Most Serious Environmental Problems According to Respondents
Source: Authors' own elaboration based on research, 2024

The interpretation must also take into account the marked concentration of responses at the positive ends of the scales. This distribution confirms broad acceptance of environmental issues but makes it more difficult to distinguish between people with a positive attitude and those for whom environmental protection is an exceptionally strong personal value. It is therefore insufficient to consider only high proportions of affirmative responses. Differences between respondents and the relationships of their attitudes with more specific behaviour, perceptions of air quality and information use are also important.

Respondents expressed a more critical perspective when evaluating existing efforts to protect and improve the environment. These efforts were considered rather or definitely insufficient by 53.9% of respondents. High awareness of environmental problems was thus accompanied by considerable dissatisfaction with how they were being addressed. Such evaluations may reflect higher expectations, dissatisfaction with visible outcomes or more

general distrust of institutions. The questionnaire does not allow these explanations to be distinguished. The finding therefore reflects respondents' opinions rather than the objective effectiveness of environmental measures.

After adjustment for multiple testing, environmental sensitivity did not differ convincingly by gender, age, student status, field of specialisation, type of settlement or region. The high importance attached to environmental issues was therefore not characteristic of only one narrowly defined group in this sample; rather, it was relatively widespread across respondents. This does not mean, however, that all population groups in Slovakia hold identical attitudes. The sampling approach and the small sizes of some subgroups do not permit such generalisation to the entire population.

From the perspective of the monograph's main topic, general environmental attitudes primarily provide a starting point for understanding the public's relationship with air quality. If most respondents consider the environment important and pollution a serious problem, communication need not begin by convincing them that environmental protection matters. Instead, it should explain why air quality is a concrete aspect of everyday health and life in their town or municipality, where reliable local data can be found and how people can respond appropriately to the situation identified.

This distinction between a broadly accepted value and specific practical understanding is important throughout the monograph. Strong support for environmental protection does not mean that a person knows the local situation, understands air quality data or knows what they can do themselves. The following sections of the survey therefore trace the progression from general environmental attitudes to personal experience, practical awareness and everyday action.

11.1.2 Self-Reported Environmental Behaviour

A positive attitude towards the environment does not automatically translate into concrete action. This section therefore builds on general attitudes and shifts attention to everyday household decisions. It examines whether respondents seek to contribute personally to positive change, how often they try to reduce their environmental footprint, whether they use reusable shopping bags and which modes of transport they use. The results reflect respondents' own assessments rather than direct observations of their behaviour or calculations of its actual environmental impact.

As many as 92.7% of respondents stated that they definitely or rather try to contribute to positive environmental change. This high proportion suggests that most do not wish to perceive themselves as passive or indifferent towards the environment. However, the general wording of the question allows respondents to interpret personal contributions differently, ranging from waste sorting and energy conservation to reduced consumption or changes in transport habits. Two respondents giving the same answer may therefore undertake different activities and achieve different environmental benefits.

A more specific picture emerged from the question concerning the regularity of environmentally friendly behaviour. Among respondents able to assess the question, 41.1% reported trying to reduce their environmental footprint daily and a further 37.2% several times a week. Thus, 79.8% reported doing so at least several times a week. Approximately 13.0% made such efforts on a monthly basis, while the remainder did so less frequently or not at all. Most respondents therefore considered themselves environmentally active, although the intensity and regularity of their efforts varied.

The use of the term “environmental footprint” itself is also important when interpreting this finding. Responses indicating that respondents did not know what the term meant highlight that specialist or project-related language may not be understood by everyone. A person may sort waste, save energy or use public transport without describing these activities as reducing an environmental footprint. Public communication should therefore refer to specific actions rather than assume a shared understanding of general environmental concepts.

Regular use of reusable shopping bags was reported by 87.2% of respondents. This is a good example of a simple behaviour that has gradually become an everyday habit. It does not require substantial financial expenditure, a fundamental lifestyle change or complicated decision-making, and its significance is easy to explain. The result indicates that environmentally friendly behaviour can become widespread when it is specific, accessible and easy to repeat.

However, the high proportion using reusable bags cannot automatically be extended to more demanding decisions. Changing transport modes, heating systems or energy sources may require greater financial resources, suitable infrastructure, agreement among household members or the ability to make decisions about one’s home. A favourable result for a simple habit therefore does not mean that respondents have equivalent opportunities to implement more complex changes with potentially greater implications for air quality.

Transport behaviour provides a more realistic and varied picture of everyday actions. Cars were used by 31.0% of respondents, public transport by 26.6%, while 40.6% combined both modes and 1.8% used neither. The largest group therefore consisted of people who alternated between cars and public transport depending on the circumstances. These results do not support a simplistic distinction between environmentally responsible public transport users and irresponsible car users.

Transport choices are strongly influenced by place of residence, service availability, commuting distance, working hours and family responsibilities. Using a car therefore does not necessarily indicate a lack of environmental concern, just as using public transport is not always motivated by environmental considerations. Without more detailed information on journey frequency, distance and available alternatives, individual transport modes cannot automatically be classified as environmentally responsible or irresponsible.

The fact that a large proportion of respondents combine cars and public transport nevertheless creates opportunities for practical measures. Many people probably cannot or do not wish to give up their cars entirely, but may use public transport more often under suitable conditions. From the perspective of reducing emissions and improving air quality, the goal need not be an immediate and complete change in transport mode. Gradually shifting some journeys towards public transport, walking or cycling may also be meaningful, provided these options are safe, reliable and accessible.

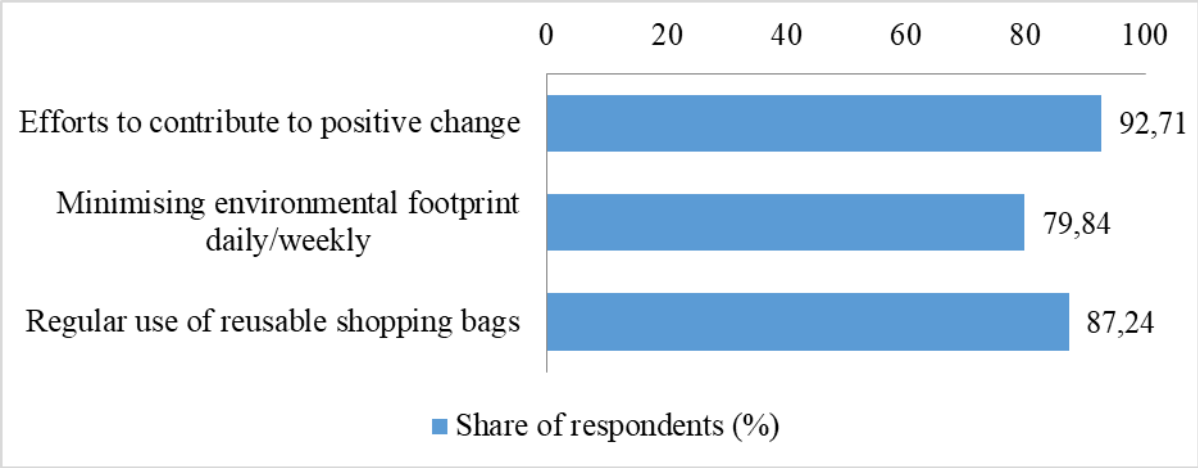


Figure 3. Respondents' Self-Reported Environmental Behaviour
Source: Authors' own elaboration based on research, 2024

The high proportions of positive responses must also be interpreted in light of possible social desirability bias. Environmental protection is a socially valued issue, and respondents may consciously or unconsciously have described their behaviour more favourably. Moreover, the questionnaire did not measure the amount of energy saved, the number of car journeys, actual waste production or other indicators that would enable the environmental benefits to be calculated. The findings therefore concern self-reported behaviour and respondents' self-perceptions, not precisely measured impacts of their households.

No convincing differences in self-reported environmental behaviour were identified by age, student status, field of specialisation, type of settlement or region. Women showed slightly more favourable values than men, but the difference was very small and did not remain significant after correction for multiple testing. The data therefore do not support a simple sociodemographic profile of a more environmentally responsible individual. It would be inappropriate to describe women, younger people, urban residents or any other group as unequivocally more environmentally conscious.

The absence of marked demographic differences does not mean that living conditions are unimportant. Basic demographic characteristics do not capture the cost of available solutions, the quality of public transport, commuting distance, home ownership, household income or the ability to make decisions about heating and energy consumption. Two people of the same age living in the same type of settlement may therefore have very different opportunities to behave in environmentally friendly ways. Rather, the results suggest that age, gender or place of residence alone are insufficient to explain everyday actions.

From an air quality perspective, the distinction between good intentions and the practical ability to make changes is crucial. Respondents predominantly expressed a willingness to contribute to environmental protection, and many simple habits were widespread. However, for behaviours that directly affect emissions—particularly transport, heating, energy consumption and waste burning—personal motivation may not be sufficient. Accessible alternatives, understandable information and conditions that enable people to make environmentally favourable choices are also necessary.

The findings in this section thus refine the picture provided by general environmental attitudes. Most respondents considered themselves environmentally active and reported regularly engaging in favourable behaviours. At the same time, individual actions differed considerably in their difficulty and dependence on external circumstances. For further assessments of air quality, it is therefore important to consider not only people's willingness

to act, but also whether they know which actions matter and have a realistic opportunity to incorporate them into everyday life.

11.1.3 Attitudes towards Energy and Mobility

Following the discussion of general environmental attitudes and everyday habits, attention turns to decisions for which there is no single, straightforwardly acceptable answer. Energy and mobility connect concerns about the environment and air quality with price, safety, infrastructure availability, trust in technology and personal experience. This section therefore examines whether high environmental sensitivity translates into support for electromobility, nuclear energy and renewable energy sources in the same way.

When specific technologies are considered, broad support for environmental protection gives way to a much more varied picture. After excluding 'Do not know' responses, 41.3% of respondents considered electromobility an environmentally appropriate solution for the future. Approximately one fifth selected the midpoint of the rating scale, while a substantial proportion expressed disagreement or doubts. Thus, electromobility was not generally rejected in the sample, but neither did it attract unequivocal consensus.

Assessments of electromobility probably encompass more than a vehicle's impact on local emissions. Respondents may have considered its price, charging availability, driving range, battery production and disposal, or the source of electricity. The response therefore represents an overall assessment of the technology, combining environmental convictions with practical and economic considerations. The questionnaire does not establish which of these factors was most important in respondents' decisions.

From an air quality perspective, electromobility is particularly relevant because it can reduce local exhaust emissions. However, electric vehicles do not entirely eliminate emissions associated with electricity generation, vehicle manufacturing, tyre and brake wear, or traffic volumes. Communication should therefore present electromobility not as the sole solution to air quality problems, but as one element of a broader transformation of transport, including public transport, walking, cycling and reducing the need for individual car journeys.

Respondents evaluated nuclear energy somewhat more favourably. Among those providing a substantive response, 53.0% described it as a clean and safe energy source. Nevertheless, this result does not indicate universal support. Nuclear energy may be perceived as a stable low-carbon source, while also raising concerns about safety, radioactive waste, costs, construction times and energy independence. People with a strong interest in the environment may therefore be found among both its supporters and opponents.

The differing evaluations of electromobility and nuclear energy show that respondents do not regard environmental technologies as a single package. An individual may support the goal of cleaner air without agreeing with every proposed means of achieving it. Technological preferences are not simply an extension of general environmental attitudes; they also reflect expected costs, confidence in safety, experience with the technology and perceptions of who will bear its consequences.

This distinction was also reflected in the relationship between environmental sensitivity and evaluations of individual technologies. Higher environmental sensitivity was associated with a more favourable attitude towards electromobility, whereas practically no comparable association emerged for nuclear energy. In public communication, electromobility is often explicitly presented as an environmentally friendly, low-emission alternative. Nuclear energy, by contrast, raises a wider range of issues in which environmental benefits intersect with safety, economic and political concerns.

When selecting energy sources that should play a greater role in the future, solar energy received the strongest support, being selected by 76.6% of respondents. Wind energy followed at 63.8%, and hydropower at 53.4%. Nuclear energy was selected by 34.6%. The results therefore indicate a marked preference for renewable sources, particularly solar and wind energy.

The lower proportion selecting nuclear energy as a preferred future source, compared with those directly assessing it as clean and safe, is not necessarily contradictory. A respondent may acknowledge some favourable properties of a technology without ranking it among the solutions they would prioritise for future development. They may prefer a source perceived as more renewable, safer, more modern or more environmentally acceptable.

The question on future energy sources allowed respondents to select multiple options. The percentages therefore cannot be added together or interpreted as proposed shares of individual sources in the energy mix. Respondents did not have to consider mutually exclusive alternatives; they may have envisaged a combination of solar, wind, hydroelectric, nuclear and other forms of energy. The results thus describe the direction of preferences, rather than a precise public vision of the future energy mix.

Strong support for solar and wind energy does not necessarily imply readiness to support every specific project. A generally favourable attitude towards renewables may change when decisions concern the siting of facilities near one's home, impacts on the landscape, electricity prices or the cost of necessary infrastructure. The questionnaire examined preferred future energy sources, not willingness to accept a particular project and its local consequences. The findings therefore cannot be used as a direct forecast of support for actual energy investments.

Five respondents used the option to specify an additional future energy source. Three mentioned geothermal or thermal energy, one hydrogen and one coal. These responses show that the options provided did not capture every technological preference. However, the number is too small to establish a percentage ranking or compare sociodemographic groups. Their main value is to illustrate the breadth of individual views on the future of energy.

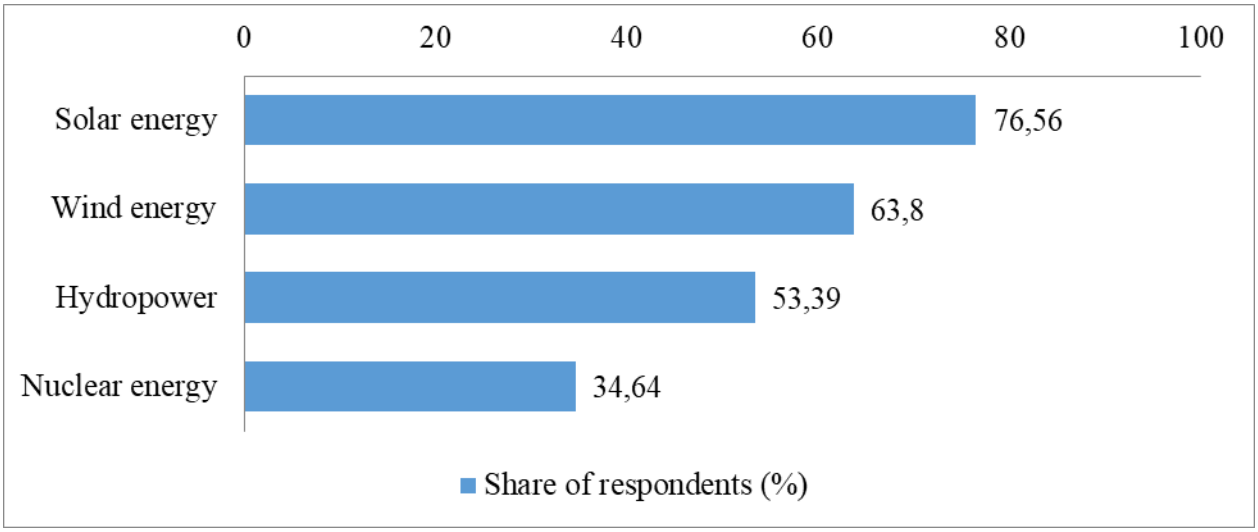


Figure 4. Preferred Energy Sources for the Future
Source: Authors' own elaboration based on research, 2024

From the perspective of the monograph's central topic, the findings show that support for better air quality does not automatically translate into support for a single technological

solution. The public may agree on the need to reduce emissions while evaluating electromobility, nuclear energy, renewables and other options differently. Communication should therefore avoid suggesting that there is only one environmentally correct technological choice. Instead, it should clearly explain the benefits, limitations, costs and local implications of individual solutions.

Energy and mobility thus add an important decision-making dimension to the understanding of air quality. The general goal of cleaner air enjoys broad support, but opinions differ on how to achieve it. The results highlight the need for communication that distinguishes the shared goal from specific technologies and helps the public understand how different solutions affect local emissions, health, costs and everyday life.

11.1.4 Perceptions of Air Quality and Its Consequences

A central part of Study 1 is the transition from general environmental issues to air quality itself. This section examines whether respondents consider air pollution a serious problem, whether they are concerned about it and whether they relate its consequences to themselves and their families. Of particular importance is the distinction between general knowledge that polluted air is harmful and the feeling that this problem affects a specific person and the place where they live.

Among respondents who provided a substantive answer, 56.8% considered air pollution in Slovakia a serious problem. A total of 13.5% answered “definitely yes” and 41.7% “rather yes”. Approximately one quarter selected the midpoint of the rating scale, 16.6% opted for “rather no” or “definitely no”, and 2.9% could not assess the situation. The result therefore does not indicate a simple division between people who acknowledge the problem and those who reject it. A substantial proportion regarded air quality as a genuine problem, although they did not always perceive it as unequivocally urgent.

Concerns about air quality were somewhat more widespread. Stronger or more moderate concern was expressed by 62.8% of respondents. The largest group selected “rather yes” (42.7%), while 20.1% reported definite concern. The typical respondent was therefore not someone experiencing constant or exceptionally intense fear, but rather someone who took the problem seriously and felt a degree of concern about it.

A similar pattern emerged for personal or family impacts. Agreement that air pollution affected respondents or their families was expressed by 60.1%. Again, the more moderate response, “rather yes”, predominated (39.6%). Approximately one fifth remained undecided, while others rejected a personal impact or were unable to assess it. The sense that the problem affected one’s own household was therefore relatively widespread, but not universal.

Responses were considerably more unequivocal regarding the general consequences of polluted air. A total of 93.4% agreed that it has long-term health effects, 88.5% acknowledged links with specific health problems and 88.2% recognised long-term damage to nature. In their overall assessment of the impacts of pollution in Slovakia, 63.3% considered the problem serious, while 22.7% selected the midpoint of the scale.

These findings reveal one of the most important distinctions in the entire survey. Respondents largely accept the general information that polluted air harms health and nature. However, they are less unequivocal in judging whether air quality is a serious problem in Slovakia itself and whether it affects their own households. Most are therefore aware of the problem, but not everyone perceives it as an immediate part of their lives.

This distinction may also be explained by the fact that air pollution is not always directly visible. Whereas some environmental problems can be observed immediately, air

quality often cannot be reliably assessed from appearance, smell or personal impressions alone. A person may know that pollution harms health but, without accessible local data, may not know whether the problem is present in their municipality, town or immediate surroundings.

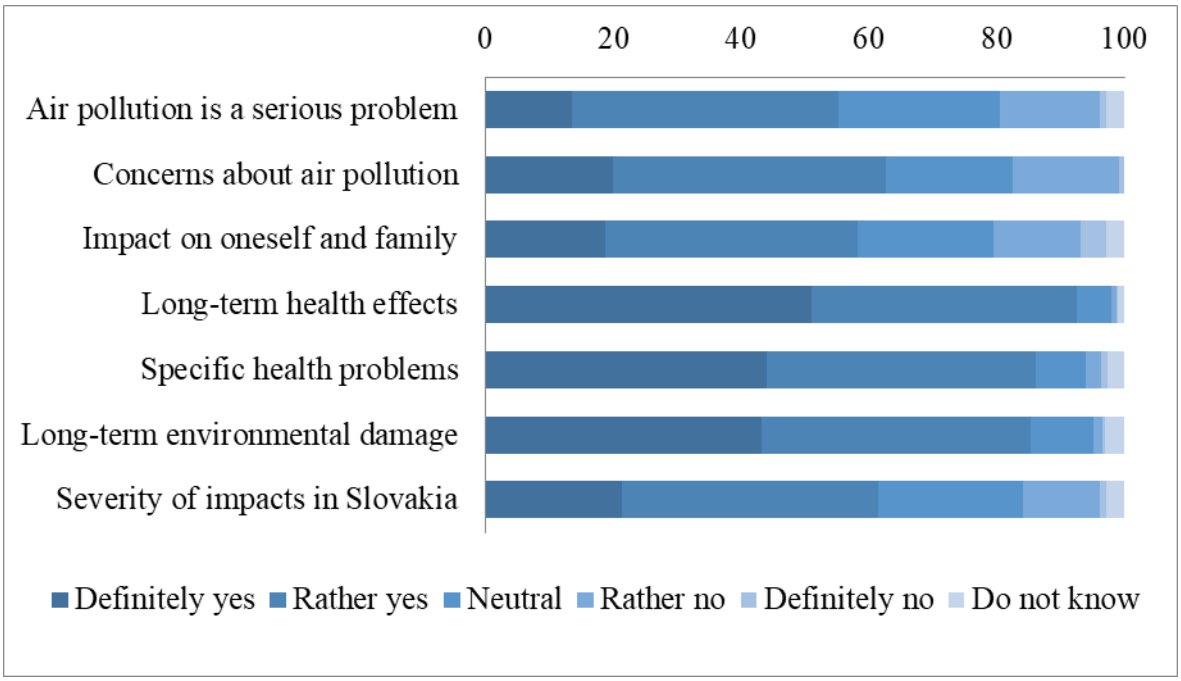


Figure 5. Distribution of Responses Concerning the Perceived Severity and Consequences of Air Pollution
Note: Percentages in the figure are based on the full sample (N = 384), including "Do not know" responses. Selected percentages discussed in the text exclude "Do not know" responses and are calculated from the number of respondents providing a substantive answer.
Source: Authors' own elaboration based on research, 2024

The questions concerning severity, concern and personal impacts were closely interconnected. Assessing air quality as a serious problem was strongly associated with concern. Respondents who regarded the problem as more serious generally also expressed greater concern. This relationship partly reflects the conceptual similarity of the two questions, but also shows that rational assessments and emotional concern tended to move together in respondents' answers.

A somewhat weaker, but still substantial, relationship emerged between perceived severity and perceived personal or family impacts. Knowing that air pollution is a serious problem is not quite the same as feeling that it affects one's own household. Personal impact represents a further step in bringing general knowledge closer to everyday life.

Perceived personal or family impacts were also associated with assessments of changes in air quality at respondents' places of residence. Deteriorating local air quality was perceived by 48.7% of respondents, 26.0% considered conditions unchanged, 9.6% reported improvement and 15.6% were unable to assess the trend. Thus, almost one in six respondents had no clear idea of how air quality was changing in their surroundings.

An inability to assess local trends should not automatically be interpreted as a lack of interest. Rather, it may suggest that respondents lack readily accessible data, are unfamiliar with longer-term trends or do not know how to interpret the information correctly. This is an

important finding for education and communication. Publishing a current value is not enough; the public needs to understand what it means, how it changes over time and whether it poses a risk to health or ordinary daily activities.

The most pronounced differences in risk perception emerged in relation to subjectively assessed local trends. Respondents who perceived deteriorating air quality had a median overall risk-perception score of 4.29. The median was 3.43 among those who did not perceive deterioration and 3.50 among those who considered conditions unchanged. In other words, respondents who felt that air quality in their surroundings had worsened perceived the overall problem considerably more intensely. Local experience may therefore be the point at which general knowledge becomes personally important. However, the data do not establish the direction of this relationship. Perceived deterioration may have increased concern, but it is equally possible that people more sensitive to environmental and health risks noticed local changes more frequently. The finding therefore describes an association, not a causal effect.

From a communication perspective, it is important that most respondents already accept the basic message that polluted air is harmful. Repeating this general statement is therefore unlikely to be sufficient. It may be more useful to explain conditions in a particular locality, which pollutants are measured, what the recorded values mean for health and when behaviour should be adjusted, for example with regard to ventilation, exercise or prolonged outdoor activities.

Perceptions of air quality risks increased slightly with age. Older respondents therefore assessed the risks somewhat more intensely on average, although age explained only a small proportion of the differences between individuals. Higher risk perception may be related to health experiences, longer observation of changes in one's place of residence or different life circumstances. The available data do not allow these explanations to be distinguished.

When age, gender, student status, field of specialisation, type of settlement and region were considered simultaneously, the initial differences by age and student status weakened. This suggests that higher risk perception is not shaped by a single characteristic, but rather by a combination of age, life circumstances, experiences and other factors. It would therefore be inappropriate to construct a simple profile of someone who is more concerned about air quality.

After adjustment for multiple testing, no convincing differences emerged between regions. This does not mean that air quality is identical across all regions. It means only that the available sample did not demonstrate a sufficiently clear difference in subjective risk perception. An objective regional comparison would require monitoring-station data, more precise respondent locations and representative coverage of individual areas.

Overall, almost all respondents acknowledge at a general level that polluted air harms health and nature. Responses are less unequivocal when assessing conditions in Slovakia, while personal experiences and information availability influence perceptions of local and personal impacts. Connecting general knowledge with local data may be crucial in determining whether individuals begin to monitor air quality regularly and use this information in everyday decision-making.

11.1.5 Perceived Awareness and the Role of Institutions

Awareness of the risks posed by polluted air is only one aspect of public preparedness. People may know that air pollution harms human health and nature while remaining unfamiliar with conditions in their surroundings, unable to interpret published data or unaware

of the measures being implemented. This section of Study 1 therefore shifts attention from general awareness to the practical usefulness of information. It examines how informed respondents felt, how they evaluated the roles of the media and education, and whether they considered national and European legislation adequate.

The findings reveal a marked gap between recognising the general harmful effects of air pollution and feeling sufficiently informed about the issue. Although the vast majority acknowledged its long-term health consequences, only 23.2% felt adequately informed about air quality problems in Slovakia. Conversely, almost half felt rather or definitely insufficiently informed, while 23.7% selected the midpoint of the rating scale. Basic awareness of the harmful effects of air pollution was therefore widespread, but far fewer respondents felt able to navigate the subject confidently.

A similar pattern emerged in more specific areas of awareness. Only 25.8% of respondents felt adequately informed about the health effects of air pollution, and 28.4% about its environmental consequences. Differences between these areas were relatively small. The perceived lack of information was therefore not confined to one narrowly defined topic but extended across the information chain, from understanding the problem and its consequences to familiarity with available solutions.

These responses do not mean that information about air quality is unavailable. Rather, they suggest that it often does not reach people in a form that enables them to feel sufficiently well informed. A respondent may encounter news about emissions, smog episodes or health risks yet still not know the air quality in their municipality, what measured values mean or how to adapt their behaviour accordingly. The decisive factors are therefore not only the amount of information but also its clarity, local relevance, credibility and practical usefulness.

Respondents were also critical of the attention paid to air quality by the media and the education system. Only 18.2% considered media attention sufficient, whereas 55.7% rated it insufficient. For the education system, the corresponding positive proportion was 21.1%, while 53.9% considered its attention insufficient; a further 7.6% could not assess the issue. Respondents therefore did not perceive the information deficit solely as an individual problem. They also associated it with institutions from which they expect regular and comprehensible explanations of environmental issues.

In the case of the media, the issue may not simply be the number of reports devoted to pollution. The result may also reflect how air quality is communicated. A one-off report about an exceedance of pollution limits may draw attention to the problem without explaining its local causes, health implications or appropriate responses. Similarly, including the topic in school curricula does not automatically mean that young people learn to find current data, interpret them correctly and use them in everyday life. Respondents may therefore be calling not merely for more content, but for more specific and practical content.

An important perspective was provided by the question of whether respondents had encountered any solutions to air quality problems. A total of 71.1% had noticed such solutions at least at one level. The European Union was the most frequently mentioned level, selected by 31.2%. Conversely, as many as 28.9% reported that they had not encountered solutions to air quality problems anywhere. Almost three in ten respondents therefore could not recall a specific activity, measure or institution that they associated with tackling air pollution.

This does not necessarily mean that no measures are being implemented. Rather, it points to their limited visibility in public communication. If people cannot connect a particular measure with an outcome in their town or municipality, they may conclude that the problem is not being addressed. A distinct communication challenge is therefore not only to publicise the existence of programmes and legislation, but also to show what is actually changing as a result, who is responsible for the measures and what they mean for air quality in everyday surroundings.

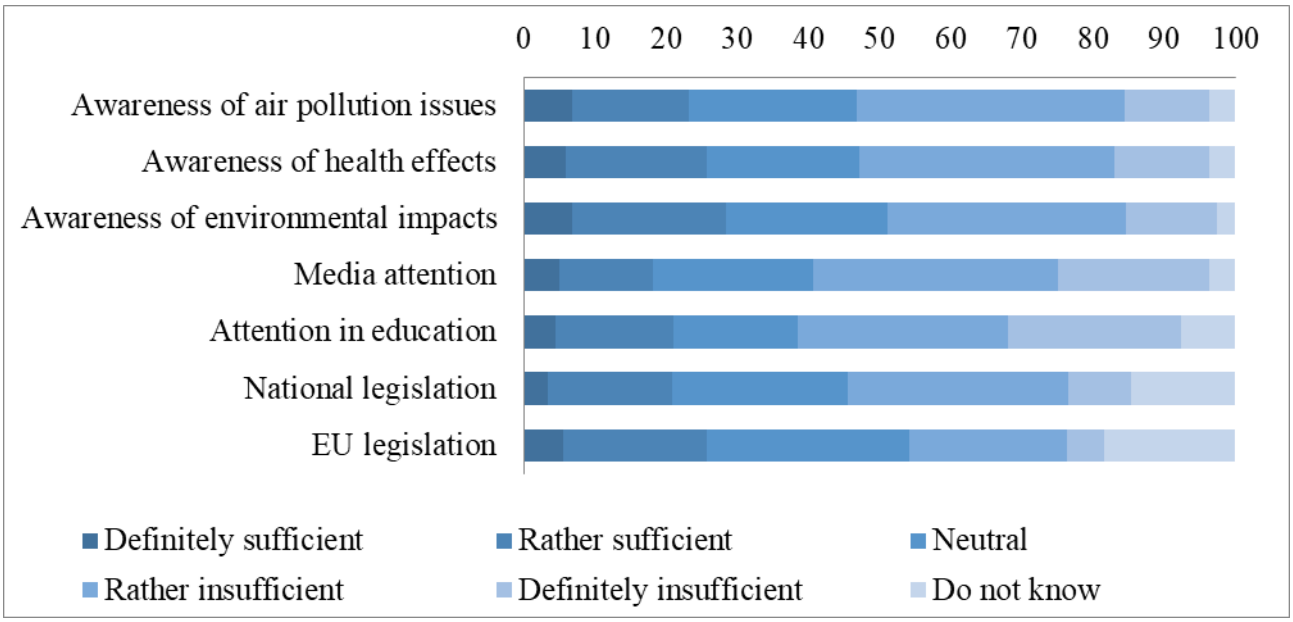


Figure 6. Perceived Awareness and Evaluations of Media, Educational and Legislative Attention
Source: Authors' own elaboration based on research, 2024

A clear association emerged between having noticed solutions and feeling informed. Respondents who had not noticed solutions at any level recorded the lowest mean awareness score, at 2.20. Among those who had noticed solutions, mean scores ranged approximately from 2.79 to 3.12, depending on the source reported.

Seeing or encountering solutions was therefore associated with higher perceived awareness. However, the direction of this relationship cannot be established from the findings. Greater visibility of measures may increase people's sense of understanding. Equally, those who are more interested in air quality and actively seek information may be more likely to notice existing solutions. In either case, communicating solutions emerges as an important component of awareness, rather than merely an addition to communication about the problem itself.

Responses were more reserved and critical when evaluating legislation. Slovak legislation was considered adequate by 20.8% of respondents. Approximately one quarter selected the midpoint of the scale, 39.9% regarded it as rather or definitely inadequate, and 14.6% did not know. The positive proportion was slightly higher for European Union legislation (25.8%). A neutral position was taken by 28.4%, 27.3% considered it inadequate, and as many as 18.5% selected 'Do not know'.

In this context, 'Do not know' responses are an important finding rather than simply missing information. Air quality regulation is a specialised field, and most members of the public do not directly encounter the specific content of legal provisions. Respondents may therefore have evaluated the visibility of outcomes and their general trust in institutions rather than the effectiveness of individual legal instruments. The greater uncertainty regarding European Union legislation suggests that people may be familiar with the broad direction of European environmental policy without knowing what obligations it entails or how these are reflected in Slovak or local practice.

The overall picture emerging from this part of the survey is relatively clear. Respondents largely knew that polluted air is harmful, but were much less likely to feel that they had sufficient information to understand a specific situation. They were critical of the

attention devoted to the issue by the media and education system, were uncertain about the adequacy of legislation, and almost one third had not noticed solutions to air quality problems anywhere. The information deficit therefore cannot be reduced to a shortage of news reports. It also encompasses poor visibility of solutions, uncertainty when assessing institutional measures and insufficient practical connections between general information and local conditions.

For air quality communication, these findings suggest that simply increasing the volume of information may not be sufficient. People need to know where to find reliable data for their place of residence, what measured values mean, when they indicate health risks and what steps they can take in a given situation. They also need to see what measures are being implemented by municipalities, the state or the European Union and what outcomes can be expected. Effective communication should therefore connect information about the problem with explanations of solutions and concrete recommendations for everyday life.

11.1.6 Evaluation of Research Assumptions

The four research assumptions in Study 1 focused on relationships between environmental sensitivity, self-reported environmental behaviour, perceptions of air quality-related risks, local experiences, perceived awareness, and evaluations of the informational and institutional environment. Their evaluation complemented the descriptive analysis by examining how these dimensions were associated with one another.

The statistical analysis primarily employed Spearman's rank correlation coefficient, while the Kruskal–Wallis test was used to assess differences in risk perception according to perceived changes in local air quality. Statistical significance was evaluated at the 0.05 level, with Holm's correction applied to account for multiple testing. Given the exploratory and cross-sectional nature of the research, the findings are interpreted as associations rather than causal relationships.

Overall Evaluation of the Research Assumptions

RA1 examined the relationship between environmental sensitivity and self-reported environmental behaviour. A statistically significant positive association was identified (Spearman's $\rho = 0.462$, Holm-adjusted $p < 0.001$). Respondents with higher environmental sensitivity tended to report more environmentally responsible behaviour. This finding suggests that stronger environmental attitudes are associated with greater self-reported efforts to reduce environmental impact. However, the results do not establish whether these reported behaviours were consistently implemented in everyday life.

RA2 focused on the association between environmental sensitivity and perceived air quality-related risks. The analysis revealed a statistically significant positive relationship (Spearman's $\rho = 0.599$, Holm-adjusted $p < 0.001$). Respondents with higher environmental sensitivity tended to perceive air pollution as a more serious problem and recognise its potential consequences for health, family, and the natural environment. This finding indicates that general environmental attitudes are closely associated with perceptions of air quality-related risks.

RA3 examined whether perceived deterioration in local air quality was associated with stronger risk perception. The Kruskal–Wallis test identified statistically significant differences in risk perception across respondents reporting deterioration, improvement, or no change in local air quality ($H = 92.627$, Holm-adjusted $p < 0.001$). Respondents perceiving deterioration

generally reported stronger air quality-related risks. The result supports the relevance of local experience, although the omnibus test alone does not establish which individual groups differ significantly.

RA4 investigated the relationship between perceived awareness and evaluations of the informational and institutional environment. A statistically significant positive association was observed (Spearman's $\rho = 0.668$, Holm-adjusted $p < 0.001$). Respondents who considered themselves better informed tended to evaluate media and educational attention to air quality, as well as the adequacy of relevant legislation, more favourably. This finding suggests that subjective awareness is associated with broader evaluations of how air quality issues are communicated and addressed by institutions.

Overall, all four research assumptions were supported by the statistical analysis. The findings indicate that environmental sensitivity is positively associated with both perceived air quality-related risks and self-reported environmental behaviour. Perceived changes in local air quality are also related to differences in risk perception, while subjective awareness is strongly associated with evaluations of the informational and institutional environment.

These results should be interpreted in light of the study's methodological limitations. The cross-sectional design does not permit causal conclusions, and the use of self-reported data may introduce response biases. Furthermore, the non-probability sampling approach limits the generalisability of the findings to the wider Slovak population.

From the perspective of the publication's central theme, the findings emphasise the importance of moving beyond general awareness of air pollution towards information that is locally relevant, understandable, and practically applicable. Communication strategies should provide accessible information about local air quality conditions, explain the meaning of monitoring results, and highlight concrete measures that individuals and institutions can take. Such an approach may help connect environmental sensitivity and perceived risks with informed everyday decisions and greater public engagement in air quality issues.

11.1.7 Key Findings on Air Quality, Study Limitations and Recommendations

Summary of the Main Findings

Study 1 provided a broader perspective on how respondents perceive environmental issues and how their general attitudes relate to the central topic of this publication: air quality. The results showed that environmental issues occupy an established place in respondents' values. The environment was considered important or very important by 81.0% of respondents; 82.2% described environmental pollution as a serious problem, and the same proportion expressed concern about pollution.

General environmental sensitivity did not, however, mean that all problems were equally important to respondents. Waste management dominated their selection of the most serious environmental problems, whereas air pollution was mentioned by 46.4%. Air quality was therefore not regarded as irrelevant, but it may not have been the first issue people recalled when compared with more visible everyday problems. Waste can be seen both at home and in public spaces, while air quality is often less apparent and requires measurements or reliable local information to assess.

Respondents also generally saw themselves as people who try to act in an environmentally responsible manner. As many as 92.7% stated that they definitely or rather tried to contribute to positive environmental change. Among respondents able to assess the question, 79.8% tried to reduce their environmental footprint daily or several times a week, and 87.2% regularly used a reusable shopping bag. These results suggest that simple,

accessible and repeatable activities have become a routine part of life for a large proportion of respondents.

The picture was more varied for more demanding decisions. Cars were used by 31.0% of respondents, public transport by 26.6%, and a combination of both by 40.6%. The largest group therefore did not consist of exclusive users of a single mode of transport, but of people who adapted their choice to the circumstances. This finding cannot be reduced to a division between environmentally responsible and irresponsible respondents. Transport behaviour is influenced by service availability, place of residence, commuting distance, work commitments and household needs.

Attitudes towards energy and technological solutions were similarly diverse. Electromobility was considered an environmentally appropriate solution for the future by 41.3% of respondents providing a substantive answer, while 53.0% assessed nuclear energy as a clean and safe source. Solar and wind energy received the greatest support among future energy sources. The results showed that high environmental sensitivity does not produce a uniform opinion on specific technologies. Respondents may consider not only environmental benefits but also price, safety, availability, practical constraints and trust in a particular solution.

With regard to air quality itself, a marked difference emerged between general awareness of its harmful effects and the perception that it poses an immediate problem. Among respondents providing substantive answers, 56.8% considered air pollution a serious problem, 62.8% expressed concern about it, and 60.1% perceived an impact on themselves or their families. Agreement with long-term health consequences reached 93.4%, with specific health-related effects 88.5%, and with long-term damage to nature 88.2%. These percentages exclude “Do not know” responses.

Most respondents therefore accepted the basic message that polluted air harms both health and nature. A smaller proportion, however, regarded it as an urgent problem for Slovakia, their place of residence or their household. The survey thus revealed a gap between general awareness and the personal relevance of the issue. Translating general knowledge into an understanding of local conditions appears to be one of the key challenges in air quality communication.

The importance of local experience was particularly evident. A deterioration in air quality where they lived was perceived by 48.7% of respondents; 26.0% considered the situation unchanged, 9.6% perceived an improvement, and 15.6% were unable to assess local developments. Respondents who reported deterioration also tended to perceive air quality-related risks more strongly. Local experience thus represented an important dimension in understanding why some respondents perceived air pollution as a more pressing issue.

The information situation nevertheless showed that many respondents did not feel sufficiently equipped to navigate the issue. Only 23.2% felt adequately informed about air quality problems in Slovakia. The corresponding proportion was 25.8% for health effects and 28.4% for environmental consequences. Thus, people generally knew that polluted air is harmful, but were much less likely to feel that they possessed sufficient concrete and usable information.

Evaluations of information providers and institutions were also critical. Only 18.2% considered media attention sufficient and 21.1% considered the attention devoted by the education system sufficient. Almost 29% could not recall any level at which they had encountered solutions to air quality problems. “Do not know” responses were also relatively frequent in evaluations of legislation, particularly European Union legislation. This suggests that existing measures may be insufficiently visible to the public or inadequately connected with concrete outcomes.

The evaluation of the four research assumptions provided additional insight into the relationships between the dimensions examined. Environmental sensitivity was positively associated with both self-reported environmentally responsible behaviour and stronger perceptions of air quality-related risks. Respondents who perceived deterioration in local air quality also reported stronger risk perceptions. In addition, higher perceived awareness was associated with more favourable evaluations of media and educational attention to air quality and the adequacy of legislation.

All four research assumptions were supported by the statistical analysis. The findings indicate that general environmental attitudes, perceptions of risks and reported behaviour are interconnected, while local experience and evaluations of the informational and institutional environment represent additional dimensions of respondents' perceptions. These associations should not be interpreted as evidence of causal relationships.

Sociodemographic differences did not allow a simple profile of an environmentally sensitive, active or informed respondent to be constructed. Environmental sensitivity and self-reported behaviour did not differ convincingly across most of the characteristics examined. A small gender difference and a difference by settlement type emerged for perceived awareness, with the suburban group reporting the highest awareness. However, this group was smaller, and the finding cannot be generalised without further verification. No convincing differences between regions were established.

The principal contribution of Study 1 therefore lies not in dividing respondents by age, gender or region, but in tracing the relationships between general environmental values, perceived air quality risks, local experiences, self-reported behaviour and perceived awareness. Respondents generally accepted that the environment matters and polluted air is harmful. The weaker point was the connection between this general awareness and local data, visible solutions and practical decision-making.

Limitations of Study 1

Several limitations must be considered when interpreting the results. The first concerns the composition of the research sample. Although sociodemographic quotas were used during recruitment, respondents were selected from an online panel rather than through probability sampling. Some sociodemographic and geographical subgroups were relatively small, particularly respondents from suburban areas. Consequently, the findings describe the surveyed sample and cannot automatically be generalised to the entire Slovak population.

The second limitation is the cross-sectional nature of the research. Data were collected during a single period, allowing associations to be identified but not their direction or cause. Where environmental sensitivity was associated with more environmentally responsible self-reported behaviour, these data cannot determine whether attitudes influenced behaviour, regular behaviour reinforced attitudes, or both were shaped by another factor.

Similarly, it cannot be determined whether perceived deterioration in local air quality increased respondents' concerns or whether people with stronger risk perceptions were more likely to notice changes in their surroundings. Repeated or longitudinal research would be needed to establish the direction of these relationships.

A third limitation is the self-reported nature of the data. The survey records what respondents said about their attitudes, knowledge and behaviour. It does not involve direct observation of their everyday behaviour or an objective calculation of households' environmental footprints. Particularly for socially valued activities, respondents may have sought to present their behaviour more favourably. High proportions reporting environmentally responsible behaviour may therefore not correspond precisely to its regularity or actual environmental impact.

Perceived awareness is likewise not an objective knowledge test. It expresses whether respondents feel that they have sufficient information. This feeling may be influenced by actual knowledge, but also by confidence, interest in the topic, information habits or general trust in the media and institutions. A more precise assessment of informational preparedness would require questions testing knowledge of information sources, air quality indicators, pollutant limits and recommended behaviour.

Subjective assessments of changes in air quality where respondents live must also be distinguished from objectively measured trends. Respondents may have based their answers on visible smog, odours, traffic intensity, local heating or media reports. Without more precise information about their location and links to monitoring-station data, it is not possible to assess the extent to which their perceptions corresponded to actual changes in pollutant concentrations.

Another limitation relates to the use of general terms. For example, “environmental footprint”, “adequacy of legislation” and “clean and safe energy source” may have had different meanings for different respondents. Broadly worded questions can evoke different forms of behaviour, measures or risks. Two respondents selecting the same answer may therefore not have drawn on the same experiences or understood the term in the same way.

The number of responses included in individual analyses also varied when questions offered a “Do not know” option. Excluding these responses from selected calculations enabled comparisons of substantive evaluations, but may also have resulted in findings that better describe respondents who were able or willing to express an opinion. The proportion of “Do not know” responses therefore remains an important part of the interpretation, particularly for legislation, technological solutions and local air quality.

The statistical evaluation of the research assumptions also involved constructing indicators from selected questionnaire items. Although these indicators enabled the examination of broader relationships, their interpretation depends on the conceptual relevance of the included items and the consistency of the resulting measures. Given the exploratory nature of the analysis, the findings should be considered evidence of associations within the surveyed sample rather than definitive validation of the underlying constructs.

Open-ended responses provided only limited qualitative material. Their number was too small to support independent thematic conclusions or comparisons between groups. They could be used to illustrate individual views and issues not included among the response options, but not as evidence of how widespread those views were.

Finally, a large proportion of responses concerning environmental attitudes were concentrated at the positive ends of the scales. This indicates broad acceptance of environmental values, but also reduces the ability of the items to distinguish between respondents with positive and exceptionally strong environmental attitudes. It was therefore necessary to consider not only percentages of agreement but also relationships between the dimensions examined.

Recommendations Arising from the Findings

The findings of Study 1 show that air quality communication need not begin by persuading the public that pollution is harmful. The vast majority of respondents already accepted this general message. Greater scope for improvement lies in connecting general knowledge with specific places, times and everyday decisions.

Strengthen the local dimension of communication. Information should enable people to find out easily what air quality is like in their town or municipality, how it changes over time and which sources have the greatest influence. Regularly updated local summaries, simple maps, easily understood colour-coded indicators and brief explanations of trends are

appropriate. A concentration value without context may not be sufficiently meaningful to the general public.

Connect data with practical recommendations. People need to know not only that air quality has deteriorated, but also what this means for an ordinary day. Communication should explain when strenuous outdoor activity should be limited, how to approach ventilation, which population groups face the greatest risks and where more detailed information can be found. Recommendations should be concrete, brief and proportionate to the severity of the situation.

Increase the visibility of implemented solutions. Almost one third of respondents had not encountered solutions to air quality problems anywhere. Institutions should therefore communicate not only the adoption of a strategy, project or legal provision, but also its concrete significance and achieved outcomes. People need to see the link between a measure and changes in transport, heating, industry or air quality monitoring.

Improve connections between European, national and local levels. Respondents most frequently encountered solutions at European Union level, but may not know how European rules affect their region. Communication should explain the pathway from a European or national measure to a concrete local outcome. Legislation should be presented through its practical consequences rather than only through technical names and formal obligations.

Make media coverage more regular and practical. Since most respondents considered media attention insufficient, air quality should be incorporated into regular reporting, much like weather forecasts or pollen reports. Coverage should not be limited to exceptional smog episodes. Long-term trends, explanations of pollution sources, seasonal differences and ways to protect health are also important.

Develop education focused on using information. School education should go beyond general explanations of pollution. Pupils and students should learn to find local data, understand the Air Quality Index, identify the main pollutants and assess the credibility of information sources. Suitable activities include tasks using data from their own region, simple measurements and connections between environmental topics, health and everyday behaviour.

Distinguish between simple and more demanding behavioural changes. The high proportion of reusable shopping-bag users shows that accessible and repeatable measures can become social norms. However, changes in transport, heating or energy sources cannot be encouraged solely by appealing to personal responsibility. They require accessible infrastructure, financially viable alternatives and solutions that reflect household circumstances.

Distinguish perceived awareness from practical preparedness. The positive association between perceived awareness and evaluations of the informational and institutional environment suggests that respondents' feelings of being informed are connected with their broader perceptions of communication and institutional responses. However, perceived awareness should not be treated as equivalent to objectively verified knowledge. The success of information activities should therefore also be assessed through respondents' ability to find local data, interpret them correctly, identify recommended measures and distinguish credible sources.

Take account of groups more vulnerable to health consequences. Information should be particularly understandable for parents of children, older people, pregnant women and people with respiratory or cardiovascular conditions. Merely identifying them as vulnerable groups is insufficient; they need clear guidance on what to do when air quality deteriorates.

Continue regular monitoring of public attitudes. Future research should use a probability-based or otherwise more robust and geographically balanced sampling approach, record respondents' place of residence more precisely and link subjective responses with

objective air quality data. Repeated measurements in different seasons would be valuable, since experience of pollution may be affected by the heating season, traffic, weather or smog episodes.

Supplement subjective assessments with tests of knowledge and behaviour. In addition to perceived awareness, future research should examine specific knowledge of the Air Quality Index, monitoring sources, health recommendations and ways to reduce emissions. It would also be useful to compare self-reported behaviour with actual use of information sources or real household decisions.

Overall, Study 1 showed that basic environmental awareness was relatively strong among surveyed respondents, but was not sufficient on its own. The greatest scope for improvement lies between general knowledge of the problem and the ability to understand its local significance and respond appropriately. Future communication should therefore focus not only on increasing concern, but above all on providing understandable data, visible solutions and realistic opportunities for action. In this way, air quality can move from an abstract environmental topic to a comprehensible part of health protection and everyday life.

11.2 Study 2: Awareness, Experiences and Readiness to Act on Air Quality

11.2.1 Understanding and Perceptions of Air Pollution Sources

Study 2 begins by examining how people understand the concept of air pollution itself. Knowing that the problem exists is not sufficient: practical understanding also requires the ability to identify its sources and at least the main types of pollutants. This section compares respondents' overall sense of understanding with more specific knowledge and shows the areas in which their confidence exceeds their detailed familiarity with the subject.

A total of 69.0% of respondents described their understanding of the issue as good or very good. However, self-assessment must not be confused with an objective knowledge test. Familiarity with specific pollutants was uneven: 66.9% reported a high level of knowledge of carbon monoxide, 54.4% of ground-level ozone, 53.1% of nitrogen oxides, 44.8% of sulphur oxides and only 35.7% of particulate matter.

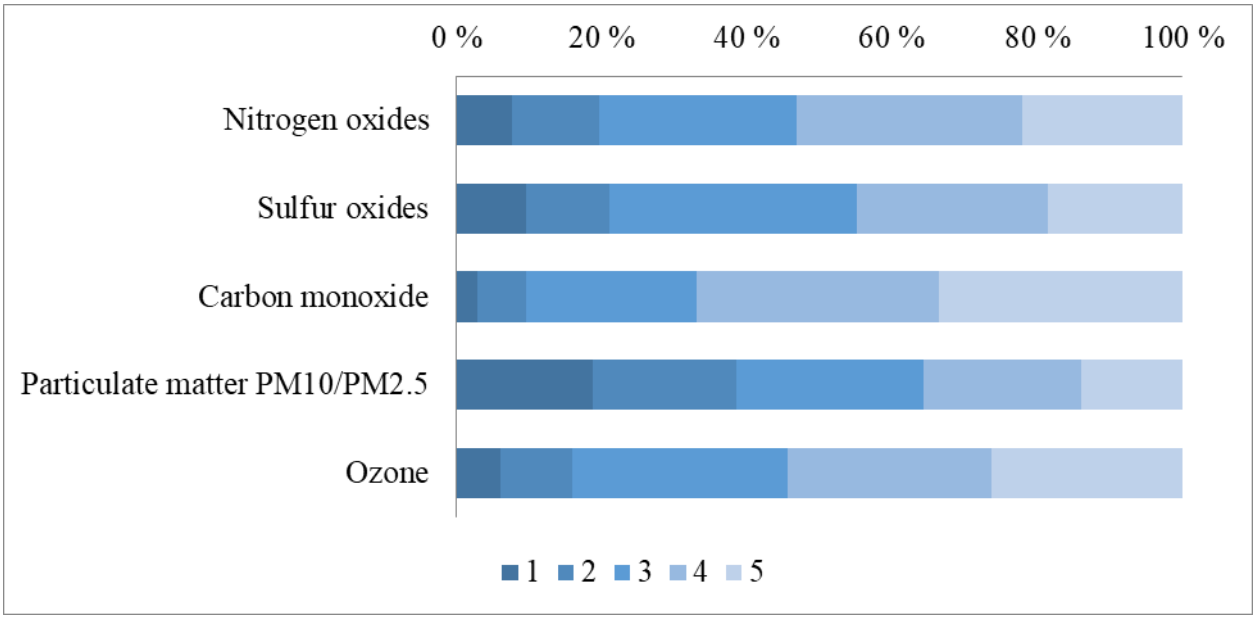


Figure 7. Self-Reported Knowledge of Selected Air Pollutants
Note: The figure presents respondents' self-assessed knowledge of selected air pollutants on a five-point rating scale, where 1 indicates the lowest level of perceived knowledge and 5 indicates the highest level. The results reflect subjective assessments rather than objectively verified knowledge.
Source: Authors' own elaboration based on research, 2024

The largest knowledge gap, concerning particulate matter, is important in practical terms. A person may open a website displaying a PM10 or PM2.5 reading without knowing whether it refers to a gas, dust, particle size or a health recommendation. If an information system uses a technical abbreviation without a brief explanation, it makes the data formally available but does not necessarily convey their meaning.

At the national level, respondents primarily associated air pollution with large, visible sources: industry (85.4%), fossil fuels (66.4%) and transport (65.6%). Approximately one third identified household heating with solid fuels, while fewer than one fifth selected construction. The public perception of the problem thus centres on major emitters, whereas dispersed emissions from numerous households or construction sites may receive less attention.

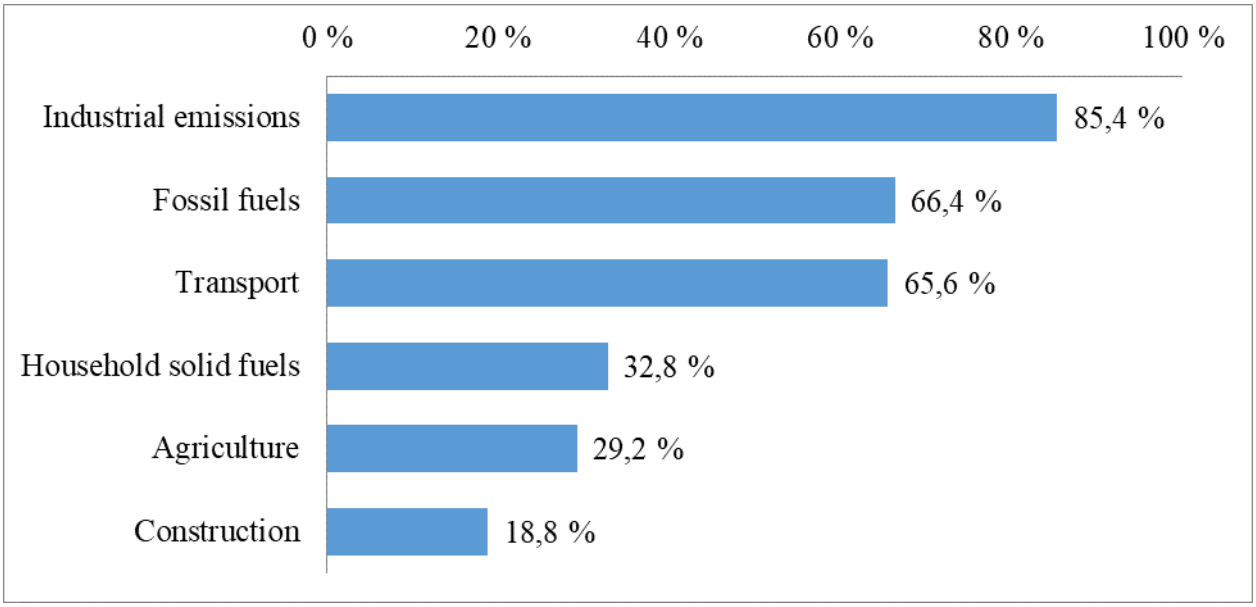


Figure 8. Perceived General Sources of Air Pollution
Source: Authors' own elaboration based on research, 2024

11.2.2 Perceived Consequences, Personal Relevance and Local Sources

Following the examination of general understanding, attention turns to how closely respondents feel the problem affects them. This section distinguishes general recognition of health and environmental consequences from experiences in the place of residence and the sense that pollution affects one's own life. It also compares perceptions of pollution sources at the national level with what people observe in their immediate surroundings.

A strong impact of pollution on health was reported by 85.9% of respondents, and the same proportion (85.9%) perceived a strong impact on the environment and climate. Perceptions of general consequences were therefore high and concentrated towards the upper end of the scale. However, 43.8% considered pollution a frequent or constant problem in their locality, while 44.8% reported a strong personal impact.

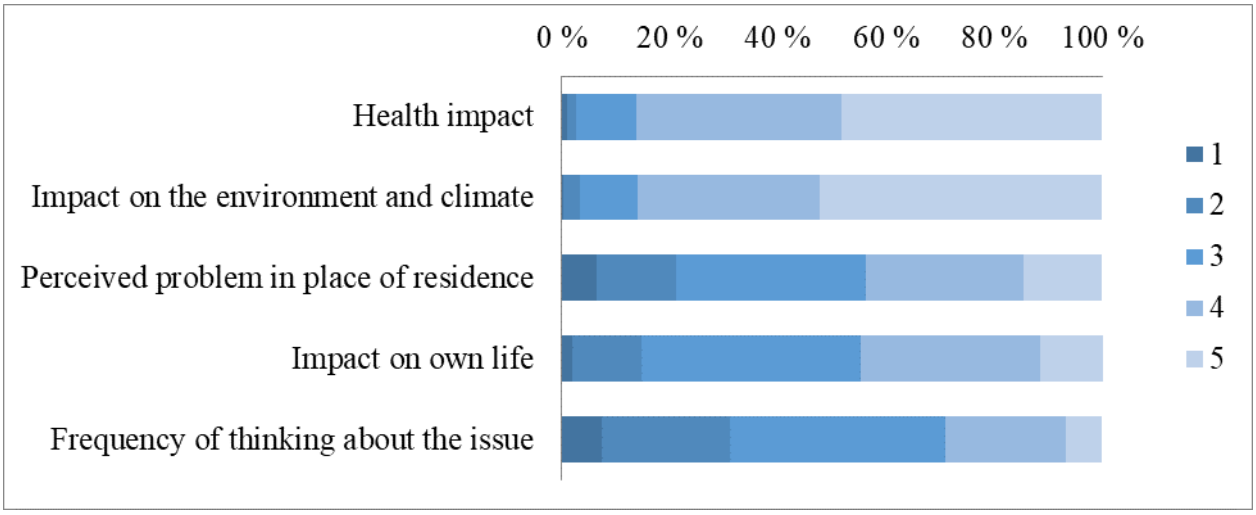


Figure 9. Consequences and Personal/Local Relevance
Note: The figure presents respondents' assessments of the perceived consequences and personal or local relevance of air pollution on a five-point rating scale, with higher values indicating a stronger perceived impact or greater relevance.
Source: Authors' own elaboration based on research, 2024

Respondents identified transport (66.1%), industry (54.9%) and waste burning (40.1%) as the main local sources. Heating with solid fuels was mentioned by 22.9%, Saharan dust by 19.0%, and construction and agriculture by 15.4% each. The local ranking differs from the general one: transport overtook industry, while waste burning became a more prominent category.

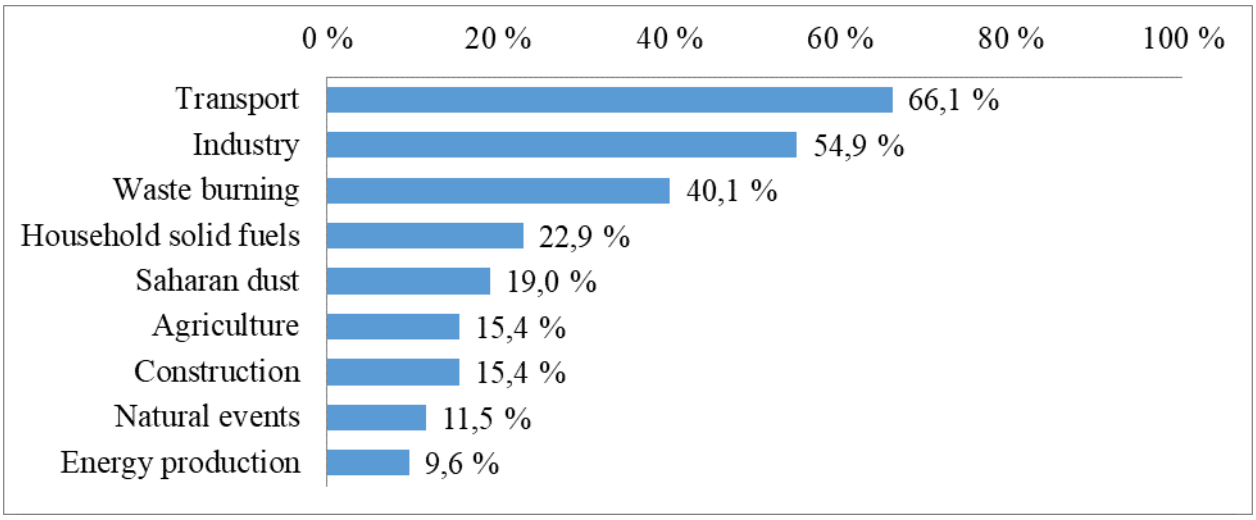


Figure 10. Perceived Sources of Pollution in the Place of Residence
Source: Authors' own elaboration based on research, 2024

Respondents assessed the impact of pollution on health and on the environment in very similar ways. In both cases, 85.9% described the impact as strong. Almost half selected the highest response option for health, and more than half did so for the environment. At a general level, therefore, there was little disagreement about whether pollution is harmful.

When the question shifted to the place of residence, however, responses were much more evenly distributed. Some 43.8% perceived pollution as a frequent or constant problem,

34.9% selected the midpoint of the scale, and approximately one fifth perceived little or no problem. The typical respondent was therefore neither someone who ignored local pollution nor someone who experienced it constantly. A large group occupied the less clearly defined space between these two positions.

A similar pattern emerged for personal impact: 44.8% reported a strong effect on their own lives, while 40.4% selected precisely the midpoint of the scale. Only 14.9% leaned towards little or no impact. A midpoint response may indicate uncertainty, occasional experience, or a sense that the problem exists but cannot readily be separated from other influences.

When assessing changes in local air quality, the largest group believed that conditions had remained unchanged (45.1%). Deterioration was perceived by 38.0%, improvement by 7.6%, and 9.4% were unable to answer. This finding also matters for communication: a general message that "the situation is alarming" may not correspond to the everyday observations of almost half of respondents.

The perspective changes when respondents consider local sources. Transport was selected by 66.1%, industry by 54.9% and waste burning by 40.1%. Waste burning is considerably more prominent locally than in an abstract assessment of the country as a whole, because smoke and odour are experienced at a specific time and place. Such experiences may be more persuasive to an individual than distant figures on national emissions.

Heating sources illustrate how opportunities for action depend on household circumstances. Gas was reported by 39.8%, district heating by 21.6%, electric heating by 11.7%, wood by 10.4% and heat pumps by 7.0%. Presenting a change in heating as a simple personal decision would therefore be misleading: many people live with a system that they cannot change independently or quickly.

Ultimately, general agreement that pollution is harmful and personal experience are not opposing perspectives. They represent different degrees of proximity to the same problem. Effective communication must connect them: from explaining the health implications, through local measurements, to realistic recommendations for a particular household.

11.2.3 Health Problems and Perceived Vulnerability

Air pollution becomes personally meaningful particularly when individuals associate it with their health. This section examines which health problems respondents attributed to poor air quality and which population groups they considered most vulnerable. The findings describe subjective experiences and public perceptions; they are not substitutes for a medical diagnosis or objective exposure measurements.

The most frequently reported problem attributed to poor air quality was irritation of the eyes, nose or throat (42.2%), followed by headaches (35.4%), fatigue or difficulty concentrating (34.1%), allergies (33.1%), and coughing, sneezing or shortness of breath (30.5%). Respiratory illness was reported by 16.4% and cardiovascular problems by 8.6%. It must be emphasised, however, that these were respondents' subjective assessments, not health conditions confirmed by medical examinations or objective measurements of exposure to pollutants. The symptoms mentioned may arise from several factors and therefore cannot be attributed unequivocally to air pollution. From the perspective of research into environmental attitudes, it is nevertheless significant that respondents subjectively associated these problems with environmental quality.

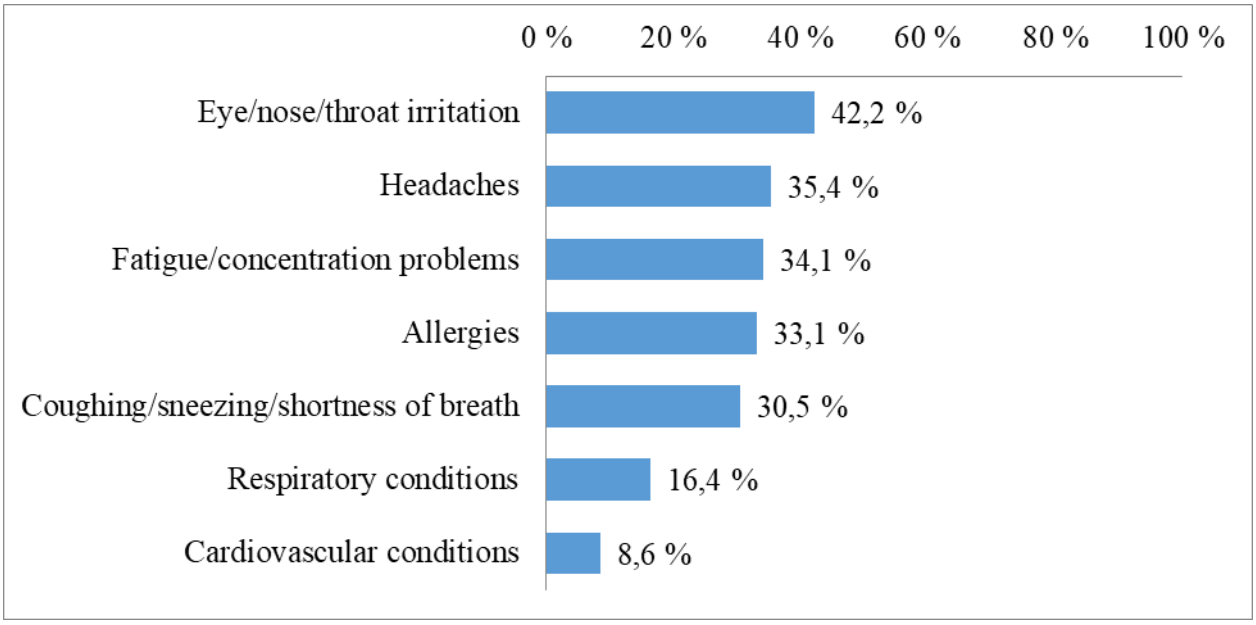


Figure 11. Health Problems Attributed to Poor Air Quality
Source: Authors' own elaboration based on research, 2024

The research findings indicated an association between the number of health problems that respondents attributed to air pollution and the degree of personal and local importance they assigned to the issue. Respondents who reported a greater number of health problems also attached greater importance to air pollution in their personal lives and places of residence. This association suggests that subjective health experiences may play an important role in shaping perceptions of environmental risks.

Regarding the frequency of adverse health effects, respondents most commonly reported experiencing them occasionally (47.7%). Health problems were experienced several times a month by 17.4%, several times a week by 13.5%, and daily by 7.0%. No adverse health effects were experienced by 14.3% of respondents. These findings suggest that, although a substantial proportion of respondents perceived a connection between air quality and their own health, this was generally an occasional rather than a regular daily experience.

When assessing which population groups were most at risk from the adverse effects of air pollution, 42.7% of respondents considered everyone to be equally at risk. Children and older people were identified by 29.9% of respondents, while 22.4% selected individuals with pre-existing health problems. These findings point to a relatively widespread perception of air pollution as a general health risk.

The survey also examined how frequently respondents thought about the possible health consequences of air pollution. A total of 28.9% considered the issue often or very often, while 39.8% selected the midpoint of the frequency scale. Approximately one third reported thinking about the health consequences only rarely or never. The findings suggest that, despite general awareness of health risks, air quality is not a subject of regular attention for most respondents.

Overall, the findings suggest that subjectively attributed health problems are an important factor associated with the personal and local significance of air pollution. Respondents reporting more health symptoms also perceived air quality as more important in their everyday lives. The findings further highlight the importance of targeted environmental communication that provides the public with accessible information on health risks, particularly vulnerable population groups, and ways to protect health when air quality deteriorates.

11.2.4 Air Quality Monitoring, the Air Quality Index and Information-Seeking Behaviour

General awareness becomes practically useful only when individuals can find current local information, understand it and use it in their decisions. The following section therefore traces the progression from awareness that air quality is monitored, through familiarity with the Air Quality Index (AQI), to actually checking data before outdoor activities or ventilating indoor spaces.

As many as 82.8% knew that air quality is monitored. However, when asked specifically how it is measured, 45.3% selected the correct answer and half chose "Do not know". Only 25.0% were aware of public reports linking health and air quality, and 24.7% knew a reliable source of current local information. Although 80.7% had at least encountered the Air Quality Index, only 10.4% monitored it regularly.

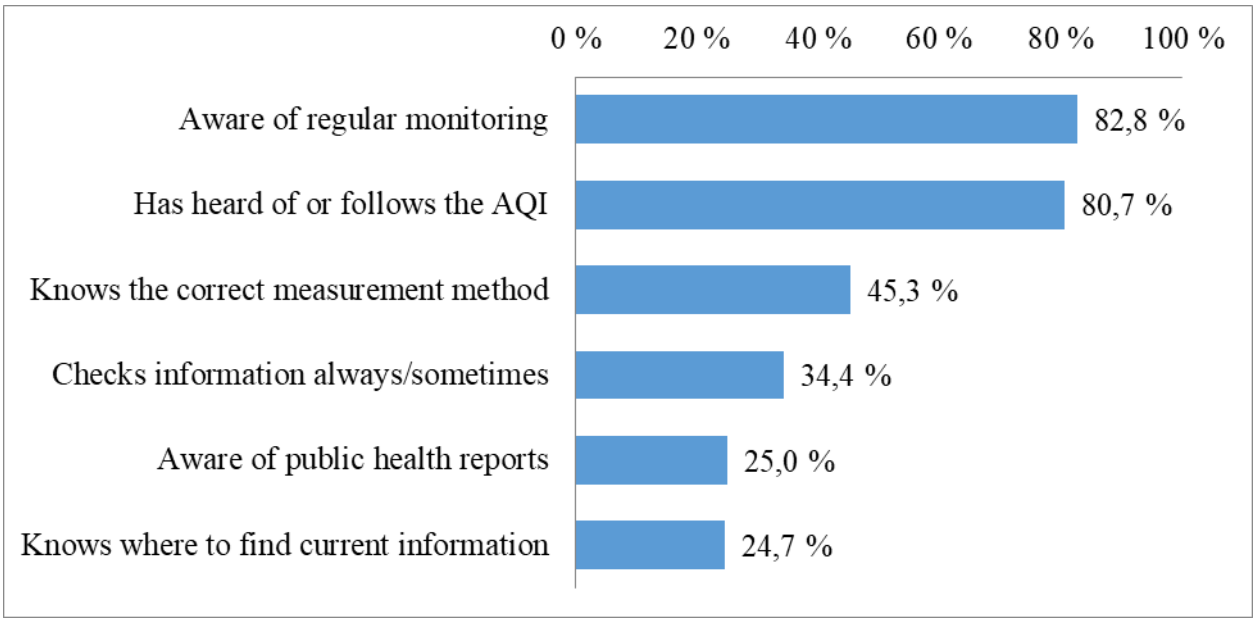


Figure 12. Familiarity with Air Quality Monitoring
Source: Authors' own elaboration based on research, 2024

Local information was checked always or sometimes by 34.4% of respondents, whereas 39.3% stated that they had not known this was possible. A strong intention to use local information in the future was reported by 33.9%.

Monitoring is the point at which an abstract issue can become an everyday tool. As many as 82.8% of respondents knew that air quality is measured regularly. Yet when asked how it is measured, 45.3% chose the correct answer and exactly half answered "Do not know". Thus, the public largely trusts that measurements are being taken but does not fully understand how the data are produced.

The gap is even greater in relation to local information. Only 15.6% considered themselves well or very well informed about current air quality where they lived. Almost half felt poorly informed or not informed at all, and one third selected the midpoint of the scale. This is a stronger signal than general awareness of monitoring: the system exists, but many people do not associate its outputs with the places where they live.

A total of 80.7% of respondents had encountered the term Air Quality Index at some point, yet only 10.4% monitored it regularly. Most respondents therefore cannot be described

as uninformed in the sense of never having heard the term. The problem lies in the transition from recognising the concept to using it regularly and meaningfully.

Approximately one quarter could name a reliable source of current local information. In the open-ended responses, the Slovak Hydrometeorological Institute (SHMÚ) was mentioned most often, alongside Google, weather websites, mobile applications and local measuring devices. The answers reveal two things simultaneously: some members of the public know the official source, while others conflate meteorological services, search engines and monitoring without clearly distinguishing the origin and reliability of the information.

Before planning an outdoor activity or ventilating indoor spaces, 3.9% always checked local information and 30.5% did so sometimes. A lack of interest was reported by 26.3%, but an even larger group (39.3%) did not know that such information could be checked. These two responses cannot be addressed with the same message. Those who are not interested need to understand the benefits; those who are unaware need simple instructions and direct access.

A total of 33.9% definitely or probably intended to use local information in the future, almost half selected the midpoint, and 21.1% indicated a low intention to do so. The large neutral group represents a genuine opportunity: these respondents have not yet developed the habit, but neither do they explicitly reject it. Whether the habit develops may depend on ease of use, automatic alerts and clear recommendations about what to do when air quality deteriorates.

A reliable source of local data was named by 95 respondents, representing 24.7% of the entire sample. SHMÚ, or a meteorological or hydrometeorological institute, appeared in 62 responses (65.3% of the 95). A general website, search engine or weather website was mentioned by 19 respondents (20.0%); a mobile application or AQI by eight (8.4%); a local sensor, information board or municipal source by six (6.3%); another public or specialist source by four (4.2%); and television by one respondent (1.1%).

The open-ended responses confirm that SHMÚ is the most prominent authority spontaneously recalled by respondents. At the same time, some respondents did not distinguish between the original data source and the channel through which they accessed it. Google, a weather application or a search engine may display data from various sources. Communication should therefore teach people not only “where to click”, but also how to verify the origin and meaning of the value displayed.

11.2.5 Awareness of Measures and Evaluation of Their Effectiveness

The next section shifts from measuring the problem to addressing it. It examines whether respondents are familiar with specific measures implemented in Slovakia and the European Union and whether they are able to evaluate them. When interpreting the results, it is important to distinguish between awareness that a measure exists, the ability to name it spontaneously, and confidence in its effectiveness.

At least one measure implemented in Slovakia was known to 14.6% of respondents, while 22.1% knew of a measure at EU level. When evaluating effectiveness, 16.7% selected “Do not know” for Slovakia and 16.9% for the EU. Among all respondents, 18.0% considered measures effective or very effective in Slovakia, compared with 18.5% for the EU.

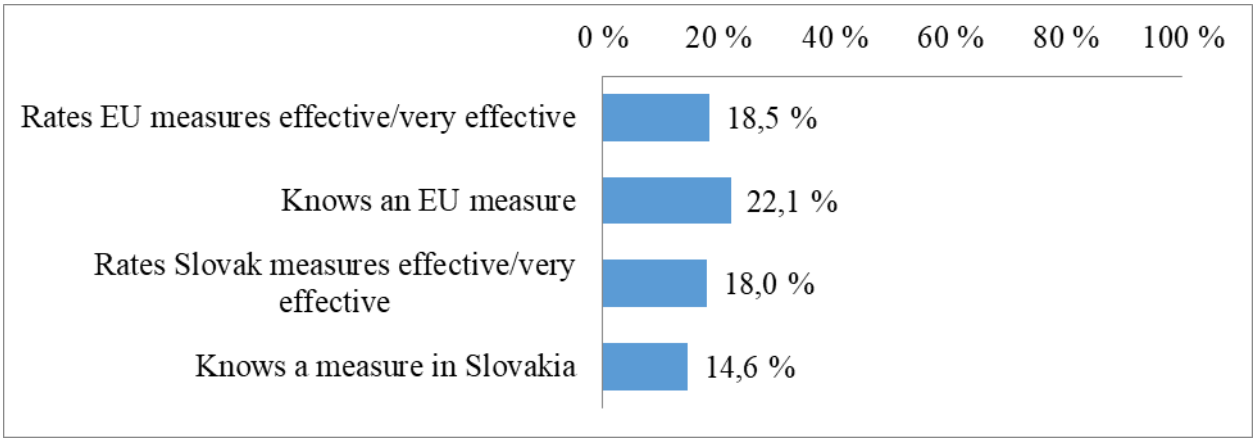


Figure 13. Awareness of Measures and Evaluation of Their Effectiveness in Slovakia and the EU
Source: Authors' own elaboration based on research, 2024

Evaluations of effectiveness were cautious. Slovak measures were described as effective or very effective by 18.0% of all respondents; 29.9% selected the midpoint of the scale, 35.4% considered them ineffective, and 16.7% were unable to assess them. For EU measures, the positive share was 18.5%, the midpoint accounted for 41.7%, negative assessments for 22.9%, and "Do not know" responses for 16.9%. Measures at the Slovak level therefore attracted more negative assessments, whereas EU measures received more cautious, middle-of-the-scale responses.

Even familiarity with a specific measure did not automatically lead to a more favourable assessment of its effectiveness. This is understandable: a person may know about a measure precisely because they follow its shortcomings, or they may be unfamiliar with it and evaluate it on the basis of general trust. Communicating the name of a policy should therefore not be confused with building confidence in it. Confidence is more likely to be strengthened by a clear explanation of its objectives, implementation and visible outcomes.

Spontaneous recall of measures in Slovakia and the European Union was low, indicating that relatively few respondents could name a specific measure at either national or European level without prompting. Policies may be technically complex, divided among several institutions and communicated without a clear connection to everyday life. Respondents may therefore be unable to name a measure even if they have encountered its effects.

At the Slovak level, the responses were more diverse in content. Respondents mentioned industrial filters, replacement of heating equipment, planting, public transport, waste burning and support for renewable energy. They therefore tended to envisage Slovak measures as concrete interventions targeting local pollution sources. Only a smaller proportion named a programme or a clearly identifiable legal instrument.

At EU level, transport and electromobility (60.7%) dominated alongside regulatory frameworks, prohibitions, limits, quotas or named strategies (59.5%). The European level was thus associated particularly strongly with regulation and transport.

Content analysis also revealed different understandings of the term "measure" itself. While some respondents named specific technical solutions or subsidy mechanisms, others mentioned general environmental objectives, prohibitions, legislative restrictions or broader political strategies. This diversity may partly explain the absence of a statistically significant association between spontaneous knowledge of measures and assessments of their effectiveness. Respondents may not have been evaluating comparable instruments, but rather

different ideas about how the state or the European Union approaches the problem of air pollution.

Overall, the results indicate a substantial gap between general recognition of the seriousness of air pollution and specific knowledge of measures intended to address it. Although respondents largely acknowledged the negative consequences of pollution, only a minority could spontaneously identify concrete measures implemented at national or European level. Familiarity with a measure did not, in itself, guarantee a more favourable evaluation of its effectiveness. The findings therefore underline the importance of systematic and comprehensible communication about environmental policies. Such communication should not merely announce the existence of measures but should, above all, explain their objectives, implementation and concrete results. It is also important to connect national and European measures with residents' everyday experiences so that the public can better understand their practical significance and assess their effectiveness on a more informed basis.

11.2.6 Willingness to Act and the Gap Between Motivation and Practical Knowledge

Awareness has practical value when it supports feasible action. This section compares general willingness to contribute, respondents' perceived knowledge of what they can do personally, and their readiness to implement specific measures. It therefore examines whether the main barrier lies in insufficient motivation, a lack of practical knowledge, or the difficulty of implementing individual measures.

A general willingness to contribute to improving air quality was expressed by 47.1% of respondents. However, only 27.6% reported good or very good knowledge of what they could personally do. This difference shows that declared motivation was more widespread than a sense of practical competence.

Willingness to implement specific measures was high: 95.3% would sort and reduce waste, 92.2% would use energy-efficient appliances, 91.9% would refrain from burning waste, 89.8% would use renewable energy sources, and 88.3% would travel on foot. Willingness was lowest for car-sharing (50.3%) and low-emission vehicles (64.3%). These differences probably reflect not only attitudes but also infrastructure availability, costs and practical opportunities.

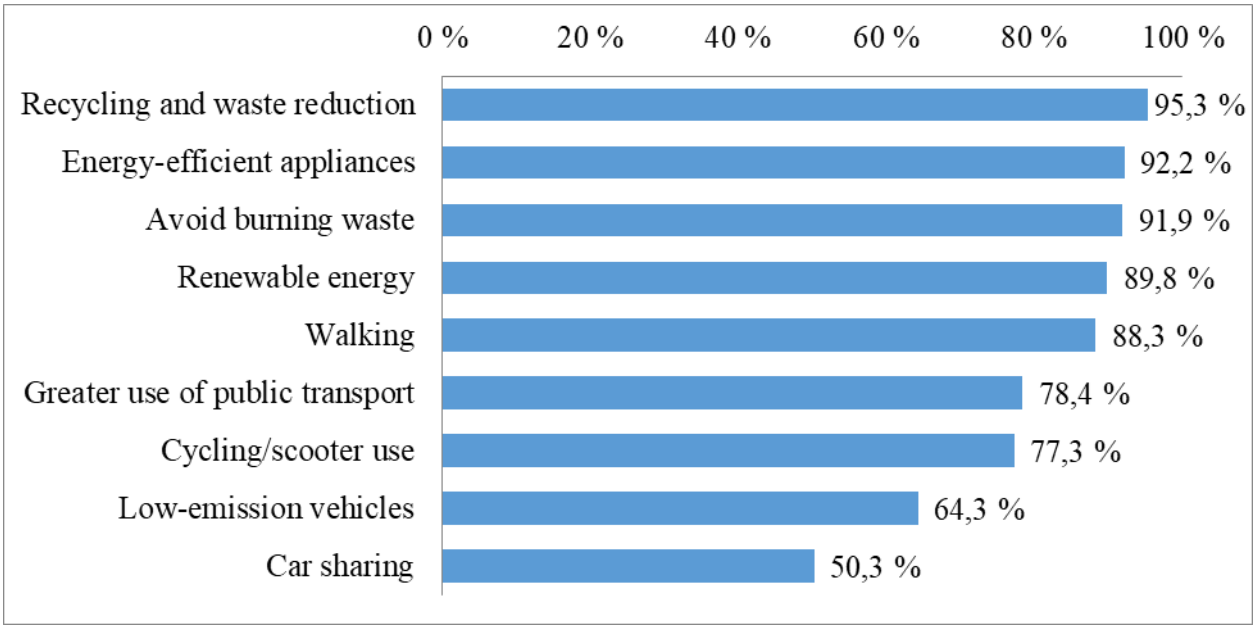


Figure 14. Declared Willingness to Implement Specific Measures
Source: Authors' own elaboration based on research, 2024

The comparatively low willingness to use car-sharing (50.3%) or a low-emission vehicle (64.3%) highlights that not every measure is equally accessible. A person may support cleaner air but have no car-sharing service nearby or lack the financial resources to replace their vehicle. Interpretation must therefore distinguish attitudes from financial and infrastructural opportunities.

For the project, this suggests a straightforward principle: communication should not stop at urging people to "behave in an environmentally responsible way". It is more useful to offer steps tailored to particular situations—what a person can do before ventilating their home, when heating, on a short journey, during a smog episode, or when making household decisions. Such communication translates good intentions into feasible choices.

The option to suggest another personal measure generated 95 non-empty written responses. After excluding "Do not know" answers, single characters, references to options already listed, and responses that were vague or humorous, 48 responses remained suitable for coding. With multiple coding permitted, the most frequent themes were waste, consumption and resource conservation (19 responses; 39.6%), transport and mobility (12; 25.0%), and direct reduction of emissions or personal exposure (9; 18.8%).

This supplementary material shows that some respondents could go beyond the options provided and identify an action of their own. At the same time, the high number of responses unsuitable for coding suggests that an open-ended request without a specific situation is challenging for many people. A practical campaign should therefore first present comprehensible options and only then invite individuals to make their own commitments.

11.2.7 Information Needs and Future Attention

The final section asks what information the public would actually find valuable. It builds on the identified gaps in knowledge of pollutants, monitoring, local data and measures.

The findings help translate the analytical results into recommendations for educational communication that is understandable, locally relevant and useful in practice.

Respondents most frequently requested practical steps individuals can take (53.6%), measures to improve air quality (52.9%), explanations of monitoring and measurement (51.8%), health risks (49.2%), and current local air quality values (47.4%). Legal frameworks attracted less interest (16.4%). The preferred form of communication is therefore practical, locally relevant and action-oriented rather than primarily legislative.

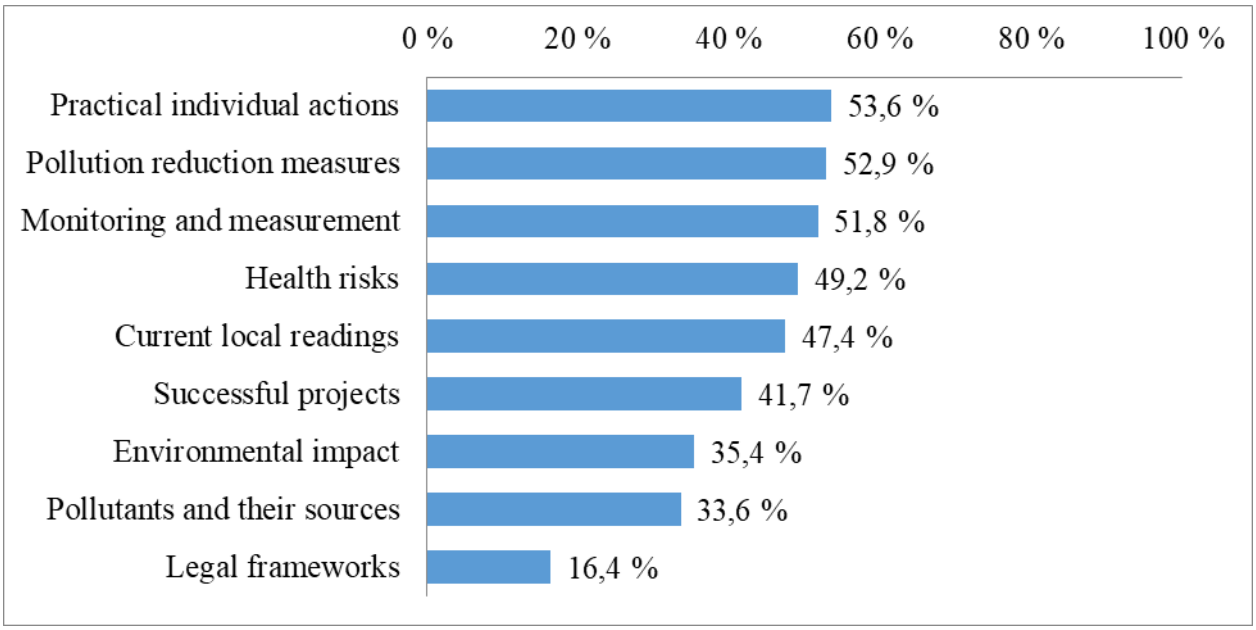


Figure 15. Preferred Content of Educational Campaigns
Source: Authors' own elaboration based on research, 2024

Preferences regarding campaign content closely mirror the gaps identified in the preceding sections. More than half of respondents wanted practical steps for individuals, specific measures to improve air quality, and explanations of monitoring. Almost half wanted information about health risks and current local values. People are therefore not merely seeking further general evidence that pollution exists; they want information translated into their own location, its implications and possible actions.

Legal frameworks were of interest to 16.4% of respondents. This should not be interpreted as a lack of interest in regulation or weaker support for air quality protection. Rather, it suggests that legal terminology is not the preferred starting point for communication. For an ordinary person, the title of a directive is less useful than an explanation of which source it regulates, what is expected to change and where that change can be observed.

The average score for intended future attention to air quality after the survey was 5.72 out of 10, with a median of 6. The highest scores of 8–10 were reported by 28.6% of respondents, although responses were distributed across the entire scale. The audience can therefore be regarded neither as indifferent nor as automatically highly engaged. A campaign needs a brief and clear entry point that is meaningful even to someone with only moderate interest.

The most accessible way to structure an information pathway may be around four questions: What is the air quality like where I live today? What does this value mean for health? Should I do anything differently today? And what is being done to improve the

situation in the long term? The findings from Study 2 indicate that the most substantial gaps currently arise between precisely these four steps.

11.2.8 Evaluation of Research Assumptions

The five research assumptions in Study 2 focused on relationships between perceived understanding of air pollution, self-reported knowledge of specific pollutants, perceived consequences, personal and local relevance, knowledge of individual actions, and willingness to act. Their evaluation complemented the descriptive findings by examining how these dimensions were associated with one another.

The statistical analysis employed Spearman's rank correlation coefficient to examine associations between the selected indicators. Statistical significance was assessed at the 0.05 level, with Holm's correction applied to account for multiple testing. Given the exploratory and cross-sectional nature of the research, the findings are interpreted as associations rather than causal relationships.

Overall Evaluation of the Research Assumptions

RA1 examined the relationship between perceived understanding of air pollution and self-reported knowledge of specific pollutants. The analysis revealed a statistically significant positive association (Spearman's $\rho = 0.377$, Holm-adjusted $p < 0.001$). Respondents who rated their general understanding of air pollution more highly also tended to report greater familiarity with individual pollutants. This moderate association suggests that perceived understanding is related to more specific self-reported knowledge. However, neither measure establishes objectively verified knowledge.

RA2 focused on the association between perceived health and environmental consequences and the personal and local relevance of air pollution. A statistically significant positive relationship was identified (Spearman's $\rho = 0.450$, Holm-adjusted $p < 0.001$). Respondents who perceived more serious consequences of air pollution also tended to regard the problem as more relevant to their own lives and surroundings. This finding highlights the connection between recognising the potential consequences of air pollution and perceiving it as a personally significant issue.

RA3 examined whether greater personal and local relevance of air pollution was associated with a higher willingness to implement specific measures. The analysis identified a statistically significant but relatively weak positive association (Spearman's $\rho = 0.224$, Holm-adjusted $p < 0.001$). Respondents who regarded air pollution as more personally relevant generally expressed a greater willingness to undertake measures aimed at improving air quality. However, the relatively small effect indicates that personal relevance alone does not adequately explain willingness to act. Furthermore, stated willingness does not demonstrate that these actions were subsequently implemented.

RA4 investigated the relationship between knowledge of possible individual actions and willingness to implement specific measures. A statistically significant but weak positive association was observed (Spearman's $\rho = 0.166$, Holm-adjusted $p = 0.001$). Respondents who reported greater knowledge of available actions tended to express slightly higher willingness to implement specific measures. This suggests that practical knowledge is associated with readiness to act, although the strength of the relationship was limited. Other factors, including financial resources, accessibility of alternatives and household circumstances, may also influence willingness to undertake particular actions.

RA5 examined the relationship between general willingness to act and subsequent attention to information about air quality. The analysis revealed a statistically significant

positive association (Spearman's $\rho = 0.316$, Holm-adjusted $p < 0.001$). Respondents who expressed a stronger willingness to contribute to improving air quality also tended to indicate a greater intention to pay attention to related information in the future. This finding suggests that general motivation to act is associated with greater openness to further information. Nevertheless, the result reflects respondents' stated intentions rather than observed information-seeking behaviour.

Overall, all five research assumptions were supported by the statistical analysis. The strongest associations were observed between perceived health and environmental consequences and personal and local relevance (RA2), followed by perceived understanding and self-reported knowledge of pollutants (RA1). The association between general willingness to act and future attention to information (RA5) was also positive. Weaker relationships were identified between personal relevance and willingness to implement specific measures (RA3), and particularly between knowledge of possible individual actions and willingness to implement them (RA4).

These findings indicate that perceived understanding, recognition of consequences, personal relevance, practical knowledge and behavioural intentions are interconnected, but the strength of these relationships varies. In particular, the weaker associations involving willingness to implement specific measures suggest that awareness and knowledge do not automatically translate into readiness to act.

The findings should be interpreted in light of the study's methodological limitations. The data were collected through a cross-sectional online questionnaire and relied primarily on respondents' subjective assessments. Consequently, the results cannot establish causal relationships or confirm that reported intentions correspond to actual behaviour. Furthermore, the non-probability sampling approach limits the generalisability of the findings to the wider Slovak population.

From the perspective of the publication's central theme, the findings emphasise the importance of moving beyond general awareness of air pollution towards information that is personally relevant, locally specific and practically applicable. Communication strategies should therefore explain the meaning of measured pollutants, demonstrate their relevance to local conditions and provide clear guidance on feasible individual measures. Such an approach may help connect general understanding and perceived risks with informed everyday decisions and greater public engagement in air quality issues.

11.2.9 Summary, Recommendations and Limitations of Study 2

Summary of the Main Findings

Study 2 showed that respondents did not lack basic awareness of air quality. Most felt that they understood the issue, knew that air quality was monitored, and recognised its substantial health and environmental consequences. However, a closer examination of specific concepts, local data and public measures revealed a more uneven level of practical understanding.

A total of 69.0% of respondents described their understanding of the issue as good or very good. However, self-reported knowledge of specific pollutants varied: carbon monoxide was the best known, whereas only 35.7% reported a high level of knowledge of particulate matter. Yet particulate matter frequently features in monitoring and health warnings. Technical abbreviations such as PM10 and PM2.5 should therefore not be used without a brief explanation of their meaning.

Respondents associated air pollution in general primarily with industry, fossil fuels and transport. In relation to their own place of residence, transport came first, while waste

burning assumed greater importance. This difference suggests that perceptions of local problems are shaped primarily by phenomena that are visible or perceptible in everyday life, such as traffic, smoke, odours or a nearby industrial facility.

A strong impact of air pollution on health and on the environment and climate was reported by approximately 85.9% of respondents in each case. Its perceived personal and local impact was considerably weaker. A frequent or persistent local problem was perceived by 43.8%, and a strong impact on their own lives by 44.8%. This again demonstrates the difference between recognising harm in general and feeling that the problem directly affects one's own life.

Health problems attributed to poor air quality were mainly immediate and non-specific: irritation of the eyes, nose or throat, headaches, fatigue, allergies and breathing difficulties. These responses reflect subjective experience rather than clinical confirmation of causation. Nevertheless, they help explain which physical symptoms make air quality personally meaningful to respondents.

The largest practical gap concerned monitoring and the use of information. Although 82.8% knew that air quality was monitored, only 45.3% correctly identified the method of measurement, 25.0% knew of public reports linking health and air quality, and 24.7% could name a reliable local information source. The Air Quality Index had been encountered by 80.7%, but only 10.4% monitored it regularly. The existence of data therefore does not, in itself, ensure that people know how to use them.

Awareness of measures was weaker than awareness of the problem itself. A specific Slovak measure was spontaneously identified by 14.6% of respondents and a European Union measure by 22.1%. Only 18.0% considered Slovak measures effective, compared with 18.5% for European Union measures. Open-ended responses indicated that respondents associated Slovak solutions primarily with emissions, transport, industry and heating, whereas European policy was perceived more broadly through regulation and environmental objectives.

Willingness to support specific measures was high, particularly for sorting and reducing waste, using energy-efficient appliances, refraining from burning waste, renewable energy and walking. It was lower for solutions requiring infrastructure or higher expenditure, such as car-sharing and low-emission vehicles. Overall willingness to act was expressed by 47.1%, but good knowledge of one's own options was reported by only a smaller proportion of respondents. This reveals a gap between motivation and the practical ability to identify suitable actions.

Respondents most often expected educational communication to provide practical individual steps, descriptions of measures, explanations of monitoring and measurement, health risks, and current local values. The survey therefore points to a central conclusion: the public does not merely need another general warning that air pollution is harmful. It needs a clear connection between local sources, measured pollutants, health implications, available actions and expected results.

The evaluation of the five research assumptions provided additional insight into these findings. A positive association was identified between perceived understanding of air pollution and self-reported knowledge of specific pollutants. The relationship between perceived health and environmental consequences and the personal and local relevance of the problem was also positive, indicating that respondents who recognised more serious consequences tended to perceive air pollution as more relevant to their own lives and surroundings.

The relationships involving willingness to act were positive but weaker. Greater personal and local relevance was associated with a higher willingness to implement specific measures, while greater reported knowledge of possible individual actions was also associated with willingness to undertake them. In addition, respondents expressing stronger general

willingness to act tended to report a greater intention to pay attention to information about air quality in the future.

All five research assumptions were supported by the statistical analysis. Nevertheless, the observed associations do not establish a causal progression from understanding to knowledge, personal relevance or actual behaviour. In particular, the relatively weak associations involving specific measures suggest that respondents' willingness to act may also depend on practical circumstances that were not fully captured by the questionnaire.

The findings therefore suggest that understanding, perceived relevance, practical knowledge and behavioural intentions are interconnected but distinct dimensions. Respondents may recognise the harmful effects of air pollution without knowing where to obtain local information or which measures are feasible in their households. Similarly, declared willingness to act should not be interpreted as evidence of subsequent behavioural change.

The principal contribution of Study 2 lies in identifying these differences between general understanding and practical preparedness. While respondents demonstrated substantial awareness of the consequences of air pollution, more limited familiarity with monitoring, reliable local information sources and public measures suggests that effective communication should place greater emphasis on the practical use of information.

Limitations of Study 2

Several limitations must be considered when interpreting the findings. First, respondents were recruited through an online panel using sociodemographic quotas rather than probability sampling. Although this approach enabled the inclusion of respondents with different characteristics, some sociodemographic and geographical subgroups remained relatively small. This was particularly evident among respondents living in suburban areas. The results therefore describe the surveyed sample and cannot automatically be generalised to the entire Slovak population.

The study was cross-sectional, with data collected during a single period. The observed associations do not establish the direction of influence. For example, it is not possible to determine whether greater personal relevance encourages willingness to implement measures or whether respondents already motivated to act are more likely to perceive air pollution as personally relevant.

Similarly, the association between knowledge of individual actions and willingness to implement them does not establish whether knowledge increases motivation or whether motivated respondents actively seek information about possible measures. Longitudinal or experimental research would be required to investigate these relationships more directly.

Most indicators were based on self-assessment. Reported understanding, knowledge of pollutants, willingness to act and future intentions may not accurately reflect objective knowledge or actual behaviour. Responses may have been influenced by social desirability, memory, differences in self-confidence and individual interpretations of the terms used.

The statistical evaluation also relied on indicators constructed from selected questionnaire items. Although these enabled the examination of broader relationships, their interpretation depends on the conceptual relevance and measurement properties of the included items. The exploratory nature of the analysis should therefore be considered when interpreting the statistical findings.

Questions concerning health problems captured symptoms that respondents themselves attributed to poor air quality. These were neither medically confirmed diagnoses nor objective measurements of exposure. Irritation of mucous membranes, headaches, fatigue

and allergic symptoms can have multiple causes; therefore, the responses cannot establish a causal health effect of air pollution.

Subjective evaluations of local air pollution were not linked to monitoring-station data or precise residential locations. Responses may have been based on odours, smoke, traffic, heating, media reports or general attitudes. Consequently, they do not describe objective trends in air quality across individual regions.

An additional limitation concerns the distinction between recognising information and being able to use it. Familiarity with the Air Quality Index, awareness of monitoring and self-reported knowledge of pollutants do not necessarily demonstrate an ability to interpret actual measurements or make appropriate decisions. Future research should therefore include practical knowledge tasks and assessments of respondents' ability to use real air quality information.

The number of valid responses could also vary between questions, particularly where respondents selected “Do not know” or where specific questions applied only to particular groups. Such responses should be considered when interpreting the results because uncertainty and inability to identify information sources are themselves relevant findings.

Open-ended responses provided useful supplementary insights, particularly regarding information sources and public measures. However, the number of respondents providing such answers was limited, and some responses could be assigned to more than one thematic category. Their findings should therefore be interpreted as descriptive rather than representative of the broader population.

Study 2 involved different respondents from Study 1. Differences between their results therefore cannot be interpreted as changes within individuals, the effects of workshops or a conventional before-and-after intervention effect. Any comparison between the two studies can describe only differences between two independent samples.

Recommendations Arising from the Findings

Translate technical terminology into everyday language. Abbreviations such as PM10, PM2.5 and AQI should always be accompanied by a brief explanation of what is measured, why the value matters and how people should use it. The relatively low level of self-reported knowledge of particulate matter shows that technical labels alone are insufficient.

Connect the general problem with people's places of residence. Communication should offer simple local maps, trends over time and explanations of the main pollution sources in a municipality or town. The positive association between perceived consequences and personal and local relevance reinforces the importance of presenting air quality information in a locally meaningful context.

Simplify access to trustworthy data. As only approximately one quarter of respondents could name a reliable local source, a single, memorable point of access linking current values, health implications and recommended behaviour would be useful. In open-ended responses, the Slovak Hydrometeorological Institute (SHMÚ) emerged as the most frequently recognised trustworthy source.

Build a habit of checking information, rather than merely awareness of monitoring. High awareness of the existence of monitoring contrasted with infrequent regular checking of the index. The positive association between general willingness to act and future attention to information suggests that motivated respondents may be particularly receptive to accessible and regularly updated information. Notifications linked to current conditions, weather, outdoor activities or ventilation decisions could help make these data part of everyday decision-making.

Communicate health risks accurately and sensitively. It is important to explain that pollution affects everyone, while children, older people and individuals with existing health conditions may be more vulnerable. Subjective symptoms should neither be dismissed nor automatically treated as proof that air pollution caused them.

Make measures and their results visible. For both national and European measures, communication should explain who implements them, which source of pollution they address, what outcomes are expected and how their effects are measured. The title of a strategy or legal instrument, without a visible local result, may not strengthen public trust.

Offer steps appropriate to households' circumstances. Recommendations should distinguish immediate, low-cost actions; changes that require accessible infrastructure; and investment decisions. This would allow people to select realistic options without the assumption that everyone can readily change their mode of transport, vehicle or heating system.

Build on existing willingness to act. Strong support for specific measures provides a favourable starting point. The positive, although relatively weak, association between knowledge of individual actions and willingness to implement them suggests that practical information may be relevant to respondents' readiness to act. Communication should therefore provide clear procedures, estimated costs, available support and explanations of expected benefits. However, these findings do not demonstrate that information alone is sufficient to produce behavioural change.

Distinguish perceived knowledge from practical competence. The positive relationship between perceived understanding and self-reported knowledge of pollutants indicates that these dimensions are associated, but neither provides objective evidence of knowledge. Educational activities should therefore assess whether people can identify pollutants, interpret monitoring values and select appropriate responses to specific air quality conditions.

Continue with more precise research. Future studies should use a probability-based or otherwise more robust and geographically balanced sampling approach, objective knowledge tasks, more precise geographical information, monitoring-station data and repeated observations across different periods. Research combining questionnaires with behavioural measures would be particularly valuable for examining whether reported intentions translate into actual information use and individual actions.

Overall, Study 2 showed that respondents' basic awareness and motivation provide a favourable starting point, but several gaps remain between general understanding and the practical use of information. The statistical findings suggest that perceived understanding, personal relevance, knowledge of possible actions and willingness to act are positively associated, although these relationships vary in strength. Communication that connects a specific local source, clearly explained measurements, health implications, an accessible solution and measurable results may therefore offer the greatest benefit. In this way, air quality can become a subject of informed everyday decisions rather than an abstract environmental concern.

Conclusion

This monograph examined environmental attitudes, perceptions of air quality, public awareness and self-reported behaviour in Slovakia. Drawing on two independent questionnaire studies, it provided a broader understanding of how respondents perceive air pollution, how they assess their knowledge of its consequences, and how environmental attitudes, perceived risks and practical knowledge relate to their reported behaviour and willingness to act.

The findings of Study 1 indicated a high level of environmental sensitivity among respondents, considerable concern about environmental protection and predominantly positive self-reported environmental behaviour. At the same time, general recognition of the seriousness of environmental problems was not accompanied by equally high levels of perceived awareness of air quality and its local consequences. The statistical analysis demonstrated positive associations between environmental sensitivity and both self-reported environmentally responsible behaviour and perceived air quality-related risks. Perceived deterioration in local air quality was also associated with stronger risk perceptions, while higher perceived awareness was related to more favourable evaluations of media and educational attention to air quality and the adequacy of legislation. These findings highlight the importance of environmental attitudes, local experiences and the informational environment in shaping respondents' perceptions.

Study 2 extended these findings by examining self-reported knowledge of specific pollutants, understanding of air quality monitoring, awareness of public measures and willingness to act in greater detail. The results revealed a gap between general awareness of the harmful effects of air pollution and the ability to identify and use specific information in everyday life. Shortcomings were particularly apparent in respondents' understanding of monitoring and local air quality data, as well as their knowledge of measures implemented at national and European levels. The statistical analysis further demonstrated positive associations between perceived understanding and self-reported knowledge of pollutants, between perceived consequences and personal and local relevance, and between these dimensions and behavioural intentions. However, the relatively weak relationships involving willingness to implement specific measures suggest that awareness, perceived relevance and practical knowledge alone do not fully explain readiness to act.

A common finding across both studies is that general environmental awareness does not necessarily correspond to sufficient practical knowledge or readiness for environmentally responsible action. What matters is not only whether individuals recognise the seriousness of air pollution, but also whether they have access to understandable and trustworthy information, can interpret it and know what specific steps are available to them. The findings therefore highlight the need to strengthen practically oriented environmental education and communication that connects scientific knowledge with residents' everyday experiences.

From an applied perspective, the monograph emphasises the importance of accessible local air quality data, clear interpretation of monitoring results, explanations of health risks and specific recommendations for individuals and households. Transparent communication of the objectives and outcomes of measures adopted at national and European levels is equally important. Effective environmental communication should therefore go beyond raising awareness and support the public's ability to make informed decisions and identify realistic opportunities for action.

The findings should be interpreted in light of the cross-sectional research design, non-probability panel recruitment and reliance on self-reported responses. Furthermore, the two studies involved independent samples, and differences between their findings cannot be interpreted as changes in the same respondents over time. The observed statistical associations

do not establish causal relationships, while reported knowledge, behaviour and intentions may differ from objectively verified knowledge and actual behaviour. Despite these limitations, the monograph provides empirical insights that can inform the development of information, educational and public-awareness activities focused on air quality.

The principal contribution of the monograph lies in identifying the gap between general awareness of an environmental problem, specific practical knowledge and readiness to act, while demonstrating how environmental sensitivity, perceived risks, local relevance and subjective awareness are associated with different dimensions of respondents' attitudes and intentions. The results provide a foundation for developing targeted environmental communication and education that aims not only to increase public knowledge but, above all, to support its translation into practically applicable understanding and informed decision-making in everyday life.

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Beyond the Numbers:
Data Collection, Perception and Public Awareness of Air Quality in Slovakia

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