THE BUSINESS OF AIR QUALITY: GLOBAL MARKETS AND LOCAL STAKEHOLDERS

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ABSTRACT
This work investigates the global market for air quality sensors and data representation. We analyzed a comprehensive sample of players in the air quality sensor market and included a representative set of 21 very different organizations in this study. The encompasses entities, from major players like Breezometer to smaller companies focusing on hyperlocal air quality data, such as Airly and AirScape, and non-profit and community-based entities. The primary purposes of these players are to provide data and sensors, promote environmental awareness, support environmental activism projects, and assist community and government initiatives.
Air quality is a pressing issue with significant health and economic consequences, including high child mortality rates. This study delves into the challenges posed by air pollution, both globally and locally, with a particular focus on the situation in North Macedonia, whose capital, Skopje, is Europe's most polluted city and consistently exceeds EU air quality limits. The hardware and software solutions market is poised for growth, requiring substantial investment to expand community-oriented air quality efforts.
The critical need for global and localized responses to air quality challenges could be addressed through network-economy approaches. A stakeholder network of environmental pioneers, companies, government organizations, and private sensor operators contributes to powerful data sources that track polluters down and analyze specific impacts. Like historical developments like sewers and clean water access, effective air quality management must become integral to our modern world, safeguarding public health and the environment.

Keywords: *Air Pollution, Global Market vs. Local Market, Sustainable Development, Community Engagement, Sensor Market Analysis*

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1. THE PROBLEM OF CLEAN AIR

Air Quality is an important and underestimated problem that impacts everybody, especially children. “More than 5,800 children and teenagers in Europe and Central Asia died in 2019 from causes related to air pollution.” (UNICEF, 2023). “The World Health Organization has estimated that around 4,000 premature deaths a year in North Macedonia may be due to air pollution.” (Bateman, 2020).

Skopje, the most polluted city in Europe (UNEP, 2018), exceeds the EU annual limit value for PM 2.5 (Almeida et al., 2020). Mortality rates for North Macedonia are more than double compared to the European average mortality rate (36.3). They are more than six times higher when compared with the average mortality rate attributed to household and ambient air pollution (12.86) in the five largest economies in the EU (Germany, France, Italy, Spain, and the Netherlands).

“Air pollution is bad for business. Around 1.2 billion workdays are lost globally annually due to air pollution, which could reach 3.8 billion days by 2060. Employees breathing polluted air are likelier to get sick and experience reduced cognitive performance. In 2019, air pollution cost India’s economy $95 billion due to reduced productivity, work absences, and premature deaths.” according to the London-based Clean Air Fund. (Daly, 2022). The economic annual cost to Skopje is thought to be between €570 and €1470 million based on health-related issues and workforce attrition. The World Bank estimated that one-third of the country's graduates lived overseas." (Bateman, 2020)

Dominant anthropogenic sources of air pollution in Skopje include large and small-scale combustion, industrial processes, transportation, waste disposal, agriculture, and land-use change. In Skopje, residential wood combustion is probably the most significant air pollution source (FMI & MOEP, 2016; Mirakovski et al., 2020; Almeida et al., 2020) and, due to specific temporal distribution, the main driver of high wintertime pollution episodes. Biomass burning remains the largest single source of ambient air pollution.

However, other significant sources, especially fuel/residual oil burning, soil dust, and open fire burning, can and must be tackled in a much shorter time frame. Open-fire burning is among the sources with the most substantial contribution during the spring and early summer. Most pollutant concentrations in the Skopje Valley originate from local emissions and are exacerbated by the local topography. Along with poor atmospheric mixing conditions, this urban area typically displays an extremely homogeneous pollution field, both spatially and by component.

2. THE AIR QUALITY GLOBAL MARKET STUDY

As part of Project CleanBREATHE [1] (Batz et al., 2022), a multinational research initiative led by the German Magdeburg-Stendal University of Applied Sciences and the Ss. Cyril and Methodius University in Skopje, global businesses involved in air pollution were analyzed. The condensed analysis result includes over 20 entities in the air quality market, providing a representative cross-section of various organizations such as for-profit corporations, NGOs, community-based organizations, and government organizations and efforts. Their contributions were evaluated using a multidimensional matrix considering hardware, software, deployment models, data analysis, and representation factors. The wide-ranging business opportunities on a local and global scope show the diversity of the approaches taken by different companies and organizations.

The target audience for the research is the stakeholders in the industry as well as all activists involved in local initiatives to provide a sense of opportunity and urgency in creating scenarios to improve air quality. Over the last five years, the indoor air quality market has matured and received a significant boost from the COVID-19 pandemic as it addresses

controllable environments in residential and corporate spaces. Managing outdoor air quality requires collaborating with many more players, from industrial and communal polluters to influencers and public authorities, to create the insights and incentives to realize the direct and indirect economic benefits and take action.

Data were collected in September 2023 using primary and secondary data collection methods, including public databases by the Word Health Organization (WHO, 2022), company websites of hardware, software, and data providers, and business research reports by Stratview Research, (2023), Verified Market Research (2021), Fortune Business Insights (2022), Markets and Markets (2023). The study focused on the field of operation, relevant business model data, and the accessibility of their data through Apps and APIs (see Table 1). Business Websites such as Crunchbase [2], Zoominfo [3], and Apollo [4] provided background information about the companies.

The scientific interest focuses on the high diversity of the approaches in the products and services offered by different companies. What are the companies' business objectives, and how do they seek to accomplish them in regional and global markets? Based on previous research, we created a search profile that yields a representative cross-section of players in the industry. The initial goal to develop clear delineations and group the players into business, non-profit, governmental, and communal groups and to structure the representation based on hardware, software, databases, and conceptual efforts was challenged by the highly diverse approaches, products, and services offered. The analysis showed a high diversity in the courses taken with few overlapping models. The selected entities cover a wide range of concepts and software and hardware solutions.

The initial research of the organization was compiled on Google and LinkedIn and complemented by published and internal business reports. From the initial overview, 21 entries were selected to cover a wide range of fields of operations and business types. In addition to a description of their activities, the table shows three parameters that can provide a direct impact on community-driven efforts: does the organization offer a customer-facing mobile app, does the organization provide an API to their solution, and can they show a local or global map to track and monitor air quality.

Table 1: Global players in the air quality market (status: September 2023)

Company	Field of Operation	Business	App	API	map
Google/Breezometer **Israel, U.S.**	Providing environmental data via Google Maps. API, Consumer App; customized map development	Sold to Google for $200M; revenue 2022: $9M; 150% growth YOY– NASDAQ: GOOG; Alphabet Corp. market cap $1.7T	✓	✓	Map
IQAir / AirVisual/AirNow **Switzerland**	Global air quality map, AQI ranking, AirVisual Outdoor Sensor ($299); AirVisual App, API, professional sensors, industry and consumer filters, face masks; IQAir foundation for kids (global); air quality sensors for underrepresented communities	Private Company, HQ: Switzerland; founded 1963 in Germany; 500 Employees, 150 in China (2020) [Wikipedia] - IQAIr Calif: $38.1M revenue	✓	✓	Map
PlumeLabs (AccuWeather) **Paris, France**	Flow: handheld consumer air quality sensor: "spring of 2023, we made the tough decision to dedicate this knowledge, system, and tech to advancing research, raising awareness, and fostering action. As a result, Flow and Flow 2 are no longer for sale." Sold to AccuWeather in 2022 [Plumelabs]	Founded in France in 2014; raised $6.1M in 4 rounds, incl. a grant; most recent EASME - EU Executive Agency for SMEs and ODINE [Crunchbase].	✓	✓	Map
AirMatters **New Zealand**	service-based consultancy specializing in environmental air quality and workplace health exposure; Mobile App	founded 2011m revenue <$5M [Zoominfo]	✓		Map

Company	Field of Operation	Business	App	API	map
amber **India**	Weather and climate solutions for the industry; multiple APIs	Inc 2017 Datair Technology Private Limited [thecompanycheck.com/] 3 rounds $1.7M [Crunchbase]	✓	✓	
South Coast AQMD **So Calif, U.S.**	air pollution control agency for all of Orange County and major portions of Los Angeles, Riverside, and San Bernardino Counties	Gov't	✓		
Pulse Eco **North Macedonia, Switzerland**	network, DIY sensor kits, and crowdsourcing platform, which gathers and presents environmental data. Our network of sensor installations and other third-party sources gathers the data and translates them into visual information.	nonprofit, community	✓	✓	Map
Air Quality in North Macedonia	(Ministry of Environment and Physical Planning -. Public effort - free sensors and N.M. map and data analysis	Gov't			Map
AirScape (airlabs) **UK**	Real Time Street-level Air Quality Data developed in Camden, London: hyperlocal sensor network	$7M revenue p.a.; 22 employees [apollo.ai]			Map
Airly **London, UK, Kraków, Poland**	smart-city solution. Low-cost sensors. Used by>500 local authorities in over 40 countries. 5,000 sensors covering 40,000 active measurement points. Warsaw 165 sensors. [Techcrunch]	Corp -raises $8.8M since3/21- $7.4m revenue [Zoominfo]			Map
Sensor Community **Stuttgart, Germany**	Sensor.Community is a contributors-driven global sensor network that creates Open Environmental Data.	Nonprofit informal group - Open Knowledge Foundation Germany e.V.		✓	Map
Clarity Movement Co. **Berkeley, Calif. U.S.**	smart-city solution; open map; low cost ($1300) sensor - free w/ subscription	founded 2014 - investors: Kickstart Ventures, Amasia, Spero; Ser. A.: $16.7M in July 2022 [Crunchbase]			Map
Earthcare / Aircare **U.S., Germany, North Macedonia**	no map; data for insurances - focus on fire; AirCare is a product of Earthcare: global map; premium app, API	Corp	✓	✓	
EPA - US Environmental Protection Agency **U.S.**	Air Date: Air Quality Data Collected at Outdoor Monitors Across the U.S. For current air quality, visit https://AirNow.gov	Gov't			Map
AirNow **U.S.**	reports air quality using the official U.S. Air Quality Index (AQI), a partnership of the U.S. Environmental Protection Agency, NOAA, National Park Service, NASA, CDC, and tribal, state, and local air quality agencies	Gov't	✓	✓	Map
Purple Air **U.S., Utah**	PurpleAir makes sensors that empower Community Scientists who collect and share hyper-local air quality data with the public.	U.S. Corp, revenue $3.8M; 20 employees (2021) [konaequity.com]	✓	✓	Map
Zaedno za Promena (togehter for change) **North Macedonia**	Independent, socially involved cooperation to improve air quality in Macedonia.	NGO			
Breeze Technologies **Hamburg, Germany**	Breeze Technologies provides hyperlocal air quality and climate data through smart, affordable indoor and outdoor sensors and actionable environmental intelligence for corporates and cities. [datanyze.com]	founded 2015; $4.8M revenue; 15 employees (2022)		✓	Map
Spectro Technology **U.S.**	Hardware and Software for Wireless Geotechnical, Structural & Environmental Monitoring. – professional air quality handheld sensors	private corp revenue <$5M (Zoominfo)			
DRAXIS Environmental	Environmental ICT solutions - SmartCity; Envi4All app integrated into hackAIR [5]	private Greek company developing software	✓		

Company	Field of Operation	Business	App	API	map
Greece					
hackAIR - Collective awareness for air quality **Greece**	Open technology platform: information on air quality, thermal comfort and probability of forest fires in EU. Web app, mobile app; API; promotes "real feel" AQ perception; open HW sensors; open-air quality datasets.	EU Project 2017 funded via EU Horizon 2020 Grant # 688363. 2021 version funded via EU Horizon 2020 grant #. 820655	✓	✓	Map

Source: Authors' text

The analysis focuses on outdoor air quality measurement and data aggregation of anthropogenic sources of air pollution. Three objectives drive the Air Quality Sensor and Data Representation market:

- Providing data and sensors to industry players (B2B)
- Environmental citizen health and eco-activist awareness projects
- Community and government-driven efforts

Company sizes and revenues cannot be compared across the categories. Breezometer (sold to Google for $250M) and Fortune500 companies like Honeywell International Inc. (US) (NASDAQ: HON), Schneider Electric (F) (SBGSY), Haier Smart Home (China) (SSE: 600690) provide high-end equipment and data intelligence to industry players. Smaller companies focus on hyperlocal data collection and representation in communities. Installations by Airly in Kraków, Poland (Shu, 2022), (Onet, 2022), (Airly, 2023), by AirScape in Camden Town, London (Carey, 2022), by Breeze Technologies in the German towns of Hennef (VKU, 2019), and Neckarsulm (Baur, 2023), and Aircare in Skopje, North Macedonia (Bateman, 2020), define hyperlocal solutions provided by companies in close collaboration with communities.
Environmental pioneers operate in low-cost to no-cost not-for-profit environments to provide responsible tools for activists to engage citizens like HackAir [5], Zaedno za Promena [6], Sensor Community [7] Stuttgart since 2015, and Pulse Eco in Skopje [8]. Grants fund international organizations like UNDP and provide local and global air quality analysis. Government organizations like the US Environmental Protection Agency [9] or the German Umweltbundesamt [10] provide official data sources and air quality alerts.
Industry market reports see strong growth in the air quality sensor market. Stratview (2023) considers a CAGR of 8.6% in the air quality market in the B2B and B2C indoor segments as the global air quality sensor market is estimated to grow from USD 4.2 billion in 2020 to USD 6.8 billion by 2026. Markets and Markets (2023) predicts a CAGR of 7.0% from 2023 to 2028.
Significant investment will be necessary for community-oriented air-quality measurement and improvement beyond isolated local projects and enthusiast-driven efforts. Air quality management needs to become a relevant player today in the same dimension as sewers and clean water became widely available in the 19th century (De Feo et al., 2014).

3. SPECIFIC CHALLENGES IN NORTH MACEDONIA

High unemployment rates, political instability, corruption, and limited economic diversification hinder North Macedonia's development. Simultaneously, the nation grapples with significant air pollution problems, primarily driven by industrial emissions and inefficient heating systems. The economic implications are multifaceted, as healthcare costs surge due to pollution-related illnesses, reduced worker productivity impacts economic output, and concerns over air quality deter foreign investments. Furthermore, the brain drain issue, linked to financial struggles and the deteriorating quality of life caused by air pollution, exacerbates the talent and human capital drain. To address these intertwined challenges effectively, North Macedonia must pursue a comprehensive approach that includes economic diversification, cleaner technologies, urban

planning, and stricter environmental regulations, ultimately fostering sustainable development and improving citizens' well-being.

4. MACEDONIAN AIR POLLUTION BUSINESS AND STAKEHOLDER ANALYSIS

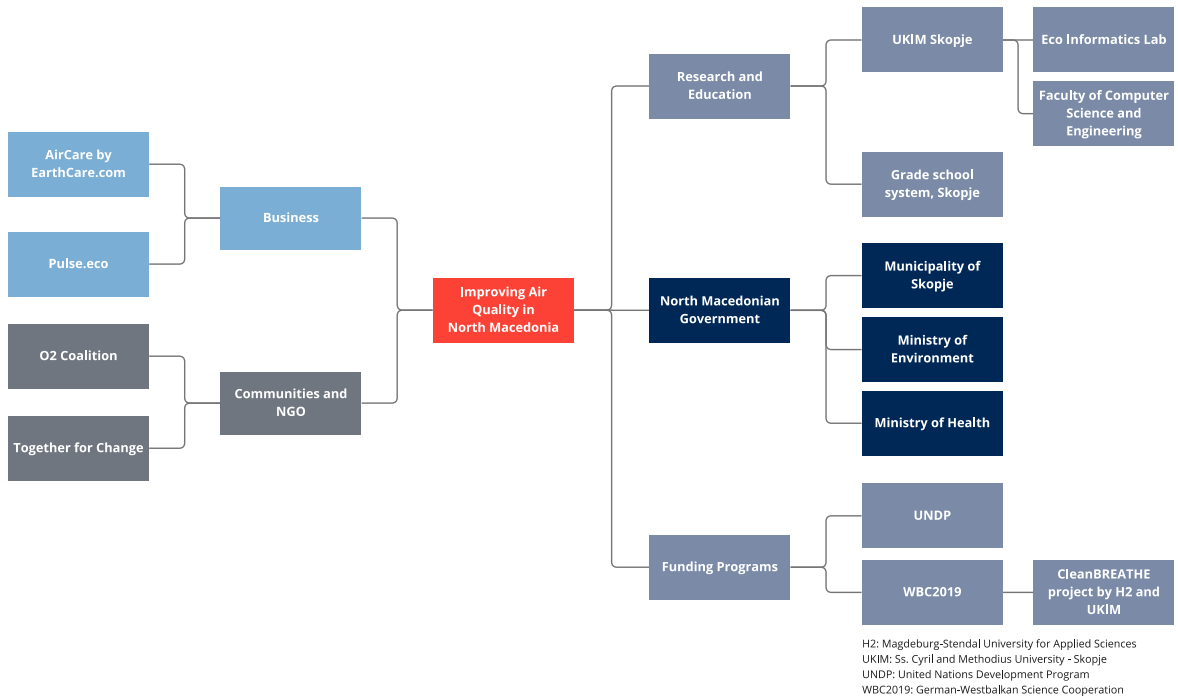
Efforts to address the worsening air quality in Northern Macedonia and surrounding countries have resulted in significant international and local initiatives. From a business perspective, two key players are vital.

Pulse.Eco [8] is a crowdsourcing platform that collects and presents environmental data from its network of sensor installations and other third-party sources. This data is then transformed into visual and easy-to-understand information using the n-things platform [11], explicitly customized for Pulse.Eco.

On the other hand, AirCare utilizes open data from government and volunteer air quality sensors to map and visualize pollution in the Balkans and beyond. This system is highly relevant for monitoring air quality and pollution while raising public awareness. Since its launch in 2014, AirCare has been actively used (with over 100,000 Android downloads) and is particularly popular during high pollution months, demonstrating the public's interest in air quality data.

Two businesses alone will have little impact. Therefore, the work of other community organizations is essential. The O2 Coalition [12] is a civil initiative that strives to promote long-lasting environmental solutions and raise awareness among citizens and students about air pollution issues. Meanwhile, "Zaedno za Promena" [3] is a citizen movement that seeks to enhance living conditions in Macedonia, with a particular emphasis on air quality. They achieve this by distributing low-cost air quality sensors for free to citizens and local governments. As improving air quality is a societal effort, more players from research, education, government, and funding organizations must be included in the stakeholder map presented in Fig. 1.

Figure 1: Stakeholder Map Addressing Air Pollution in North Macedonia



Source: Authors

Based on the literature on network economies, individual communities must find unique paths to combat air pollution, including companies and business opportunities. For example, Kraków, with a population of 780,000 residents, successfully reduced annual particulate mass concentrations through a program implemented from 2012 to 2020. Kraków's achievements were made possible through a €75M subsidy scheme encompassing various heating technologies and building modernization, resulting in the removal of 25,000 old heating units. Additionally, the city engaged its residents through open observatory maps, drone operations, thermal audits, and the imposition of fines for rule violations, demonstrating the power of localized efforts in mitigating air pollution (Jovanovska et al., 2023).

5. DEVELOPING A COHESIVE ECOSYSTEM

A cohesive ecosystem must emerge to combat air pollution, emphasizing collaboration and synergy among diverse stakeholders. Governments must set stringent environmental standards, encouraging industries to adopt sustainable practices. Concurrently, enterprises must partner with research institutions and innovate air pollution forecasting and detection technologies. Environmental organizations and NGOs need to foster public awareness, mobilize communities to participate in air pollution crowd sensing, support the development of open-air pollution data sets, and complement academic research and educational efforts. This synergy should be further propelled by technology innovators and startups developing advanced monitoring tools, aligning to mitigate air pollution.

Together, this collaborative ecosystem can manifest a shared commitment to fostering a sustainable environment, underscoring the significance of collective action in addressing the global challenge of air pollution and local-specific challenges.

Government bodies can generate revenue through fines imposed on non-compliant entities, including small and medium-sized enterprises, and taxes on emissions that incentivize adopting cleaner technologies. In addition, they already benefit from issuing environmental permits and certifications, promoting sustainable practices while creating a revenue stream.

Industries and corporations can establish revenue streams by selling eco-friendly products and services, supported by government incentives and subsidies for embracing sustainable practices. It is essential to mention the indirect benefit for the industry that can be identified by decreased migration of capable labor force.

Environmental organizations and NGOs rely on funding from grants and donations to support their environmental conservation and sustainability initiatives. They can also generate revenue through organizing educational events and providing consulting services related to environmental policy development and implementation.

Research institutions and academia secure revenue through research grants and partnerships, fostering technological transfer and licensing agreements related to pollution control and sustainable technologies. Hosting international conferences and seminars focused on environmental solutions further contributes to their revenue streams. Crowdfunding initiatives can provide financial support for community-led ecological projects and sustainability efforts.

Technology innovators and startups can establish revenue streams by selling or licensing advanced environmental technologies to industries and regulatory bodies. Funding from venture capitalists, private investors, and government grants further supports their growth and scalability in pursuing environmentally focused solutions.

This diverse range of revenue sources can ensure the sustained commitment of stakeholders in the ongoing battle against air pollution, laying the groundwork for a more sustainable and environmentally conscious future.

Initiating an ecosystem to combat air pollution demands a systematic approach grounded in academic principles and existing best practices. We believe that establishing such an ecosystem should include the following steps:

a) A comprehensive mapping of stakeholders, encompassing governmental bodies, academic institutions, industrial entities, non-governmental organizations, and community representatives, should be created (See Figure 1) to enable structured dialogues and establish a shared understanding of the challenges and a collective commitment to addressing air pollution.
b) Data collection and research to assess the current air quality state encompassing quantitative measurements of pollutants, their sources, and associated health and environmental impacts (Arsov, 2020). This type of research serves as a foundation for evidence-based policy formulation and targeted interventions.
c) Fostering interdisciplinary collaborations between academic research institutions and technology innovators to drive the development and deployment of state-of-the-art technologies for air quality monitoring, pollution control, and sustainable energy solutions. Emphasis should be given to integrating cutting-edge research findings into practical environmental management and mitigation applications.
d) Implementing community-based educational programs and awareness campaigns that leverage evidence-based research to inform and empower citizens about the detrimental effects of air pollution. Encourage active community participation in sustainable practices, fostering a culture of collective responsibility and engagement (Batz et al., 2022).
e) Developing a robust monitoring framework based on scientific methodologies, enabling systematic assessment of current air pollution.

We strongly believe we have addressed these steps within the CleanBREATHE project (Batz et al., 2022). However, to establish a functional ecosystem, more efforts should be realized, including:

a) Utilizing the insights derived from monitoring and evaluation to adapt and refine policies and interventions, ensuring continual improvement and progress toward sustainable air quality management.
b) Establishing strategic partnerships with governmental agencies, philanthropic organizations, and private sector stakeholders to secure funding for research projects, technology development, and community engagement initiatives. Establish a sustainable funding acquisition plan that aligns with the long-term goals of the ecosystem and emphasizes transparency and accountability in financial management.
c) Collaboration with regulatory authorities and policy experts to develop a comprehensive regulatory framework that aligns with international standards and best practices. Implementation mechanisms for effective policy enforcement and compliance monitoring, underpinned by systematic data collection and analysis.

6. CONCLUSION

Addressing the issue of air pollution on a global scale requires a diverse network of stakeholders and localized approaches. More than a one-size-fits-all solution will be required. It is essential to prioritize public data and deploy more sensors so companies and initiatives can work together to address the problem. Accessible data empowers citizens, policymakers, and researchers to make informed decisions and fosters stakeholder accountability.

The global Air Quality Sensor and Data Representation market serves three key objectives: B2B support, environmental awareness projects, and community/government initiatives. This market includes both industry giants and smaller hyperlocal-focused companies. Environmental pioneers and government agencies also contribute to data sources. The market is expected to grow at a CAGR of about 7%, but substantial investment is needed to expand community-oriented air quality initiatives. Most effective are not necessarily local companies but local projects and communal efforts working with international companies, as the successful projects in Kraków and Camden Town show. Like the historical development of sewers and clean water access, air quality management must become a prominent aspect of our modern world (De Feo et al., 2014). Developing successful implementations does not necessarily require local companies but should rely on providers showing best practices in their respective hardware and software fields. The case studies of the projects in Camden Town, London, and Kraków are other good examples of how a local project benefits from international collaboration.

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