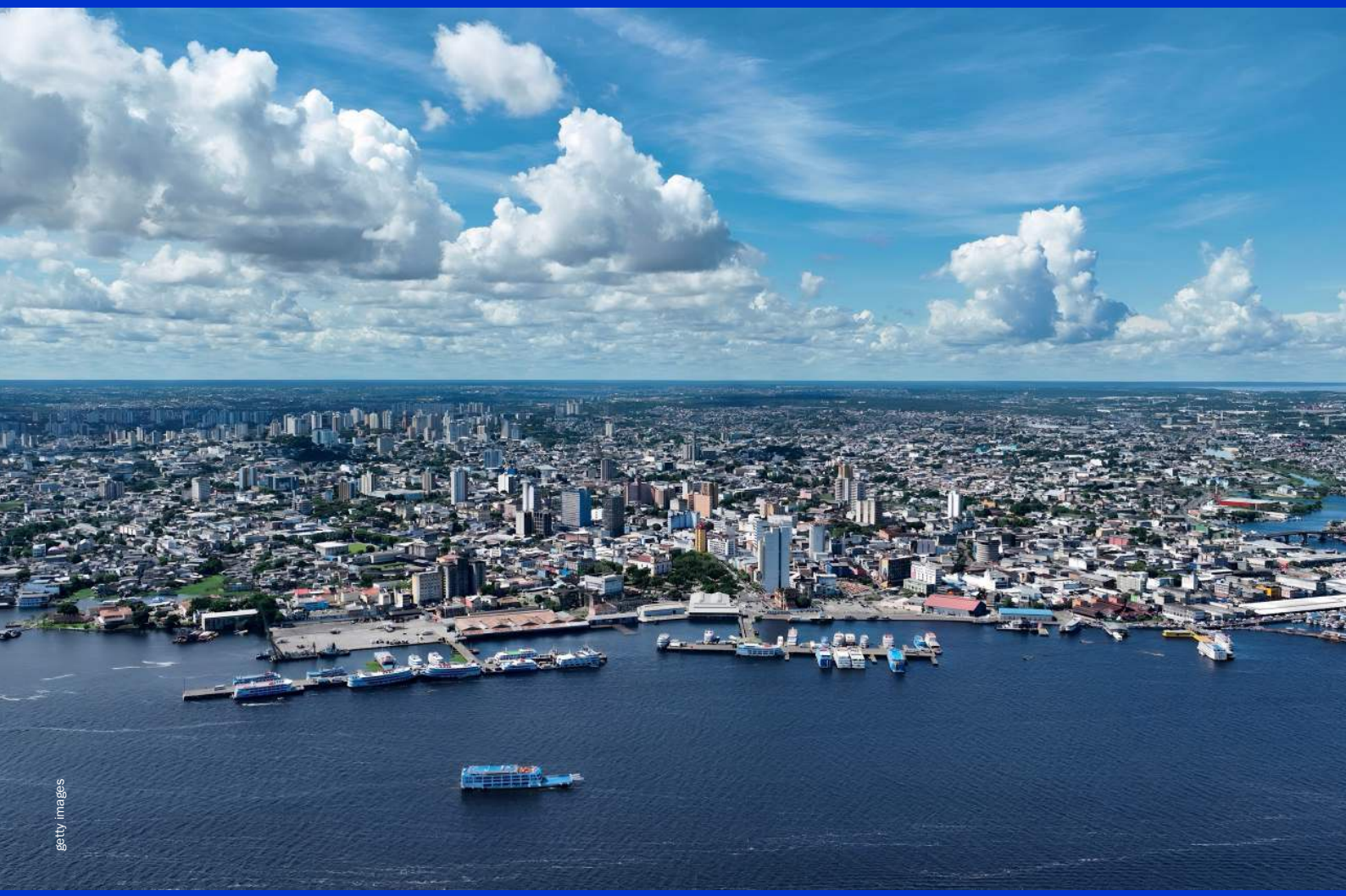
BREATHING LIFE INTO AMAZONIAN CITIES:

A Transformative Investment Case for Clean Air, Health, Equity and Economic Opportunity



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Instituto Ar

Clean Air Institute

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IN COLLABORATION WITH

MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE

BRAZILIAN GOVERNMENT BRASIL STANDING WITH THE BRAZILIAN PEOPLE

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ABOUT ENVIRONMENTAL DEFENSE FUND

EDF uses expertise in both science and economics to deliver bold, game-changing climate solutions—from rallying airlines to reach net-zero emissions, to making tropical forests more valuable when left standing and measuring neighborhood air quality on a block-by-block basis.

EDF is committed to helping people facing climate threats today and reducing climate pollution for a better tomorrow. Everything EDF does is aimed at building a vital Earth for everyone.

ABOUT INSTITUTO AR

Instituto Ar - Healthy Air Brazil is a nonprofit organization dedicated to protecting human health, with a focus on tackling climate change and air pollution. The institution turns scientific knowledge into action, influencing public policy and engaging society in the pursuit of a balanced climate and cleaner, healthier air.

ABOUT CLEAN AIR INSTITUTE

Clean Air Institute emerged out of a spin off of the Clean Air Initiative for Latin America and the Caribbean, originally launched by the World Bank and a group of the largest metropolis from the region. Established in 2006, Clean Air Institute is an independent organization driven by sustainability principles, innovation ideas and high impact actions, and a strong foundation of multiple stakeholder engagement. Learn more at cleanairinstitute.org.

ABOUT BREATHE CITIES

This publication was supported by Breathe Cities, a first-of-its kind initiative to clean the air, cut carbon emissions and enhance public health in cities around the world. Learn more at breathecities.org.

ACKNOWLEDGMENTS

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A special thanks goes to the Breathe Cities initiative, whose support and shared vision for healthier cities were essential throughout this process.

Above all, we honor the communities themselves, whose daily efforts and resilience are the strongest call to action for cleaner air, healthier lives, and greater equity across the Amazon.

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EXECUTIVE SUMMARY

The Amazon is home to more than 30 million people and over half of Brazil's Indigenous population. Its cities, now home to more than 10 million residents, are expanding rapidly. Yet, residents breathe unsafe air every day. Air pollution has become an urban crisis that costs lives, overwhelms health systems, and stifles economic growth.

This report, covering 20 Amazonian cities, sets out why urgent action is both necessary and possible. It quantifies the health and economic toll of pollution, identifies its main, and highlights practical, investable solutions that cities and their partners can implement immediately.

With COP30 on the horizon, the Amazon has a chance to show how air quality action can deliver health, equity, and climate benefits simultaneously.

THE SCALE OF THE CRISIS

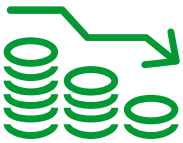
- **We estimate that over 9,000 premature deaths annually** in the Legal Amazon are linked to fine particulate matter (PM2.5) exposure, with 3,356 of these occurring in the 20 largest cities.
- **Since 2000, more than 58,000 lives have been lost** to air pollution in the region.
- **The cumulative health-related economic burden is R$2.18 trillion** (US$437 billion) from 2000 to 2023.
- **In Manaus, health costs attributable to PM2.5 exposure are equivalent to around 5% of the city's GDP** each year. Seasonal fires push $PM_{2.5}$ levels above 100 µg/m³, resulting in school closures and overwhelming hospitals.

These figures put Amazonian cities among the hardest-hit urban areas in the Americas.

Top facts

Up to 477%
increase in pollution-related deaths in some Amazon cities since 2000

Nearly 60%
potential reduction in air pollution-related deaths by achieving Brazil's 2044 PM2.5 target



$5 billion USD
in health-related costs of air pollution lost per year in 20 cities analyzed

1.5-3x more jobs
generated for every $1 million invested in clean air vs. fossil fuels

Without decisive action, the burden will likely increase as urbanization, dependency on fossil fuels, and industrial activity continue to expand.

SHARED SOURCES, SHARED SOLUTIONS

The same drivers of air pollution in these Amazonian cities also accelerate climate change:

- **Road transport accounts for approximately 11 million tons of CO_2 emissions annually**, comprising 2.3% of Brazil's total fossil fuel emissions.
- **The industry contributes approximately 3.3 million tons of CO_2 emissions annually**.
- Waste management processes, primarily uncontrolled disposal, **account for the emission of approximately 71,000 tons of methane annually**.
- **Fires and biomass burning result in the emission of over 4,000 tons of black carbon annually**.

Reducing these emissions provides immediate health benefits and advances climate and sustainability goals.

THE OPPORTUNITY

Meeting Brazil's updated air quality standards could bring transformative change to Amazon cities:

- Achieving the country's 2044 $PM_{2.5}$ target (10 µg/m^3 annual average) **would prevent 1,280 deaths in urban areas annually and avoid R$15.1 billion in costs**.
- **The greatest benefits would reach vulnerable groups, including low-income households, favela residents, and Indigenous peoples**, who are disproportionately exposed to pollution.
- **Clean energy, transportation, and cooking projects can generate two to four times their cost** in returns while creating more jobs than fossil fuel alternatives.

STRATEGIC PRIORITIES

Drawing on evidence and broad consultation conducted under this project—including regional workshops, in-person discussions in Manaus, and targeted interviews—we identified priority sectors and interventions that can deliver scalable clean air investments with fast and visible co-benefits for health, climate, equity, and the economy. The proposals are illustrative and preliminary, with cost ranges based on international benchmarks conservatively adjusted for Amazonian conditions, and are intended to inform a future multi-donor, multi-investor regional initiative aligned with federal, state, and municipal air quality and climate plans:

High-Impact, High-Feasibility Interventions (2025-2026):

- **Install advanced pollution controls** (filters, scrubbers, SCR) and Continuous Emissions Monitoring Systems in priority factories in the Manaus Free Trade Zone and Pará's industrial/mining hubs (~US$50-70M, phased).
- **In cities like Manaus, retrofitting natural-gas plants** with low-NOx burners or SCR systems can cut emissions by up to 90% at about US $40-100 per kW. Over time, combined-cycle upgrades or solar-battery hybrids could further reduce fuel use and pollution.
- **Establish a Regional Air Quality Monitoring and Early-Warning System** to address local, regional and transboundary pollution, ensure consistent and comparable data across cities, and deliver integrated health and climate alerts. The system will combine regulatory (reference grade) stations, calibrated low-cost sensors, and regional QA/QC and calibration hubs, and will be integrated with national and regional platforms such as MonitorAr, INPE Queimadas, Fiocruz, and SUS health surveillance systems. The estimated investment is ~US$10–14M, plus operation and maintenance costs, depending on network scale and configuration.

Medium-Term Strategic Interventions (2026-2028):

- **Deploy 200 battery-electric buses in Belém and Manaus**, expanding to over 500 by 2027 (~US$110-135M).
- **Transition passenger and freight fleets to low- and zero-emission propulsion**, installing shore power in major ports such as Manaus, Belém, and Santarém (first wave: ~US$150-200M).

- **Launch "Clean Air-Positive Bioeconomy Zones"** featuring zero-burning practices, renewable energy, and clean logistics for the production of açaí, aquaculture, and forest products, as well as agroforestry (~US$60-80M).

Long-Term Transformational Actions (2028-2030):

- **Expand the community fire brigade and Payment for Environmental Services pilots programs in Pará & Amazonas**. This will strengthen fire prevention and control systems, link them with air quality alerts, and incentivize fire-free practices. These efforts will cut pollution, health risks, and drivers of deforestation (~US$20-25M).
- **Connect all interventions through the Regional Air Quality Monitoring and Early-Warning System** described above, ensuring that data from reference grade stations, calibrated sensors, satellite observation and health surveillance systems are systematically integrated. This connection will allow for timely alerts, evidence-based policy design, and performance tracking.

These investments can be incorporated into major programs such as the World Bank's Amazon Pro-Sustentabilidade initiative (US$592.5M) and the IDB/GCF Amazon Bioeconomy Fund (US$598M), while also leveraging domestic resources from the Amazon Fund, BNDES, federal and state budgets, and a potential future federal fund based on the polluter-pays principle. Complemented by contributions from bilateral donors, philanthropy, and Corporate Social Responsibility (CSR), this blended finance approach would multiply returns, ensure co-benefits across health, climate, and equity outcomes, and secure long-term financial sustainability.

WHY THIS MATTERS NOW

- **The 20 cities analyzed represent the majority of Amazonian urban exposure** and mortality, chosen for their population size, pollution levels and sectoral drivers.
- **Brazil has just updated its National Air Quality Policy and Standards**, creating a new legal framework that requires implementation.
- **With COP30 in Belém, there is unprecedented global attention** and new finance streams to align air quality with climate, health, and equity goals.

THE PATH AHEAD

This report is more than just a diagnosis; it is a roadmap for action. It illustrates where investments can have the greatest impact, how interventions align with Brazil's policies, and the roles that cities, states, federal government, multilateral banks, and civil society can play.

Delaying action will result in deeper costs, greater inequity, and missed opportunities. Taking action now will lead to healthier communities, stronger economies, and a more resilient Amazon, setting a model for urban action worldwide.

EDF AND INSTITUTO AR CONVENED A HYBRID MEETING IN MANAUS, AMAZONAS, BRAZIL, BRINGING TOGETHER MEMBERS OF THE COALIZÃO RESPIRA AMAZÔNIA AND OTHER KEY STAKEHOLDERS TO VALIDATE, REFINE, AND PRIORITIZE THE PROJECT'S FINDINGS AND RECOMMENDATIONS.
(photos by Ageu Felipe de Lima)

1. CLEAN AIR CANNOT WAIT: A WAKE-UP CALL

THE TRIPLE PLANETARY THREAT IN AMAZONIA

Covering over 5 million km² across nine states of Brazil, the Legal Amazon[1] (Figure 1) holds 60% of the world's largest rainforest and river system. Its ecosystem services valued in trillions of dollars, are essential for livelihoods, national development, and global climate regulation. Yet, its cities and communities face growing challenges from urban and wildfire-driven air pollution, intensifying climate and weather extremes, and persistent health vulnerabilities. These challenges shape daily life and demand responses grounded in local realities and national priorities.

Today, the Legal Amazon is home to over 30 million people,[2] including more than half of Brazil's Indigenous peoples.[3] Urbanization has accelerated in recent decades, with our analysis

KEY POINTS

- The Amazon's cities face a triple threat: air pollution, climate extremes, and health vulnerabilities.
- Urban air quality is worsening due to unchecked industrial growth, fossil-fueled transport, and rampant biomass burning.
- Seasonal wildfires and deforestation cause dangerous pollution spikes, impacting millions.
- Most Amazonian cities lack robust air quality monitoring and enforcement.
- Immediate action is needed to prevent further health and environmental crises.

Top facts

5 million km²
area covered by the legal Amazon across the nine Brazilian states

20
Number of largest Amazon cities analyzed in this report

30 million
number of people living in the Legal Amazon

Up to 477%
increase in pollution-related deaths in some Amazon cities since 2000

estimating over 70% of inhabitants living in urban areas. Urban centers, such as Manaus, Belém, Porto Velho, and Rio Branco, are experiencing worsening air quality due to a combination of factors, including industrial emissions, road and riverine transport fleets dependent on fossil fuels, natural gas power generation, and biomass burning. Seasonal wildfires linked to deforestation, land clearing, and drought conditions intensify the problem, periodically blanketing cities in smoke causing dramatic short-term pollution spikes. Together, these sources create persistent year-round exposure punctuated by severe seasonal episodes.

METHODOLOGY

This study employed an interdisciplinary, data-driven approach to assess air pollution, its emission sources and the associated health, economic, and equity impacts across 20 Brazilian Amazonian cities.

Air Pollution Assessment

For $PM_{2.5}$ concentrations, we used a dataset that integrated information from satellite-retrieved aerosol optical depth, chemical transport modeling, and ground monitor data, to create annual average $PM_{2.5}$ concentration estimates from the year 2000 to 2023 for the 20 identified urban areas.[4] This fine resolution dataset (approximately 1 km^2) integrates information from satellite-retrieved aerosol optical depth from three satellite instruments (the Moderate Resolution Imaging Spectroradiometer, SeaWiFs, and the Multiangle Imaging Spectroradiometer), chemical transport modeling using the Goddard Earth Observing System-Chem chemical transport model, and ground monitor data. Ground-based observations of $PM_{2.5}$ were incorporated using a geographically weighted regression. While our use of a satellite-derived concentration dataset does incorporate in situ monitoring data where available, the limited air monitoring data available within the Amazonian region introduces uncertainty through the reduced capability to calibrate the model based on measured data.

FIGURE 1. GEOGRAPHICAL LOCATION OF THE LEGAL AMAZON

Emissions Characterization

We analyzed emissions data from two publicly available sources: EDGAR and BRAIN[5,6]. EDGAR is a global inventory of greenhouse gas and air pollution emissions with a resolution of 10×10km. It including three main greenhouse gases (CO_2, CH_4, N_2O), primary particulates (PM_{10}, $PM_{2.5}$, BC, OC), ozone precursor gases (CO, NO_x, NMVOC, CH_4), and acidifying gases (NH_3, NO_x, SO_2). The emission inventories are broken out into detailed economic sectors. BRAIN is a Brazil-specific, comprehensive database with 20×20km resolution over the Amazon region. It includes emissions from the transportation, industrial, wildfire/biomass burning, and biogenic sectors.

Health Impact Assessment

We used a health impact function to estimate mortality attributable to $PM_{2.5}$. The health impact function incorporates annual average $PM_{2.5}$ concentrations, population counts, baseline mortality rates, and epidemiologically derived concentration-response functions. The population-attributable fraction (PAF) is the percentage of disease in a population that can be attributed to $PM_{2.5}$, as determined by the concentration-response functions derived from the epidemiological literature.[7] We used cause-specific relative risk estimates from the GBD 2021 study for mortality from ischemic heart disease, ischemic and intracerebral hemorrhagic stroke, lower respiratory infections, lung cancer, type 2 diabetes, and chronic obstructive pulmonary disease.[8]

Gridded population count estimates are available from WorldPop for all ages from 2000 to 2020.[9] For urban area definitions, we used urban boundaries defined by the Global Human Settlement Grid.[10] For each urban area, we calculated population-weighted average $PM_{2.5}$ concentrations. We obtained country-specific, age-specific, and cause-specific baseline disease rates from the 2021 GBD study data exchange for 2000 to 2021. In the absence of a global scale dataset on urban mortality rates, we applied Brazil's national rates to Amazonian cities.

Economic Valuation

To estimate the health economic damages associated with the mortality burden of $PM_{2.5}$, we used the Value of Statistical Life (VSL) metric. According to Viscusi and Masterman (2017), the VSL for Brazil is derived from the VSL for the USA based on the income elasticity of Brazil in relation to the USA.[11] The formula is: VSL(Brazil) = VSL Central Value (USA) × (GNI per capita of Brazil / GNI per capita of USA)^Income\ elasticity^, where income elasticity is assumed to be 1.

Equity Analysis

To examine the spatial correlations between sociodemographic characteristics, $PM_{2.5}$ concentrations, and $PM_{2.5}$-attributable mortality across Brazilian Amazonian states, we integrated our pollution datasets with municipal-level resolution sociodemographic data. We analyzed the Trajetorias dataset, which is a collection of environmental, epidemiological, and economic indicators for Brazilian Legal Amazon municipalities and includes a Multidimensional Poverty Index (MPI) for rural and urban populations.[12]

WIDESPREAD AIR POLLUTION ACROSS THE LEGAL AMAZON

In the last two decades, air pollution has risen sharply across cities in the Legal Amazon. In our analysis of 20 Brazilian Amazonian cities, home to 10.7 million people, we estimate that annual average $PM_{2.5}$ concentrations range from 13.1 μg/m³ in Palmas to 38.3 μg/m³ in Porto Velho; all well above the WHO guideline of 5 μg/m³ (Figure 2, Table 2 in Appendix).

In 2023, we find that air pollution contributed to more than 3,300 premature deaths and R$24.5 billion (US $4.9 billion) in health costs. Our analysis shows that since 2000, pollution-related mortality has increased by 47% to 477% across different cities, outpacing population growth, with a cumulative toll of more than 58,000 premature deaths and an estimated USD$437 billion in economic losses. In Manaus alone, we estimate an annual average of $PM_{2.5}$ levels of 33 μg/m³, nearly double Brazil's 2025 air quality target (17 μg/m³) and over six times the WHO guideline (5 μg/m³).

The same sources that worsen local air quality, particularly biomass burning and fossil fuel combustion, also emit large amounts of CO_2 and short-lived climate pollutants such as black carbon. Cutting these emissions would not only improve air quality and protect health locally but also deliver broader benefits for regional and global climate mitigation.

The drivers of this burden are distinctive to the region. Industrial expansion in free trade zones, motorization without effective emissions control, reliance on fossil fuel for local power systems, and rapid urban growth combine with seasonal biomass burning and wildfires to generate complex pollution episodes.

WHY ACT NOW

Brazil's updated air quality standards (CONAMA Resolution 506/2024), aligned with WHO interim targets, create a strong legal foundation for action. However, fragmented responsibilities, weak enforcement, and limited monitoring capacity pose challenges in the Amazon. Conversely, Brazil's Net Zero 2050 goal, its commitments under the Paris Agreement commitments, and its participation in global coalitions present unprecedented opportunities to link air quality with climate action. This report highlights interventions—from cleaner energy and mobility to strengthened air quality monitoring, improved fire management, and health-centered urban planning—that deliver multiple co-benefits for public health and climate goals.

Beyond diagnosis, the report outlines a roadmap for action, including strengthening institutional coordination, advancing monitoring and data transparency, controlling emissions from high-impact sectors, and promoting sustainable urban and economic development models. With COP30 approaching and momentum building for Brazil's National Air Quality Policy, the time to act is now. Delaying action will result in greater costs, deeper inequities, and missed opportunities. Taking action now will lead to healthier communities, more resilient economies, and a more sustainable future for the Amazon region and beyond.

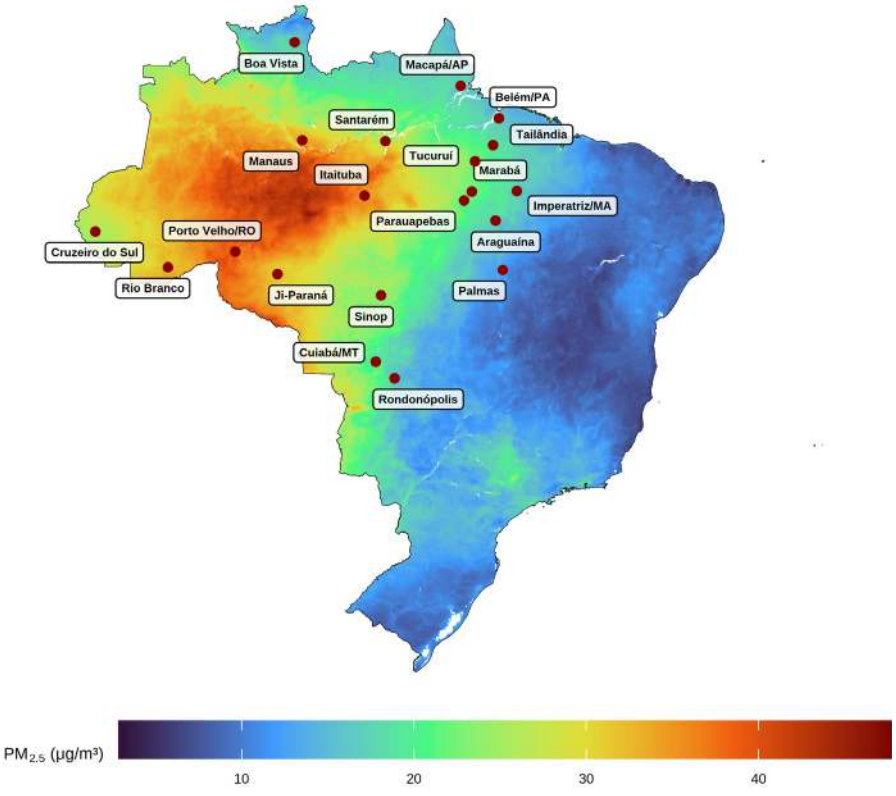


FIGURE 2. PM2.5 CONCENTRATIONS IN BRAZIL (2023).[13]

KEY FINDING

Manaus, 33.3 µg/m3 (7x WHO guidelines)

WHAT THIS MEANS

Breathing Manaus air daily equals smoking 1.5 cigarettes per day for every resident, including newborns.

WHO cigarette equivalence formula: Pope III, C.A., et al. (2009). "Fine particulate air pollution and life expectancy in the United States." New England Journal of Medicine, 360(4), 376-386.

BRAZIL'S AIR QUALITY STANDARDS (PM2.5 ANNUAL AVERAGE CONCENTRATIONS)

Brazil's 2024 air quality standards (CONAMA Resolution 506/2024) update reference values for PM2.5, and other major pollutants. Legally adopted as guidance for monitoring and management policies, they establish progressive targets a chart a pathway gradual alignment with WHO guidelines:

- Phase I (2024): Transitional period
- Phase II (2025): 17 μg/m³ (WHO Interim Target 4)
- Phase III (2033): 15 μg/m³ (WHO Interim Target 3)
- Phase IV (2044): 10 μg/m³ (WHO Interim Target 2)
- WHO Air Quality Guideline: 5 μg/m³ annual average PM2.5

KEY FINDING

$PM_{2.5}$ levels 13.1-38.3 μg/m³ across cities

WHAT THIS MEANS

Even the cleanest Amazon city has air dirtier than 95% of European cities. Porto Velho's air quality matches New Delhi during moderate pollution days.[ii]

European city air quality: European Environment Agency. (2024). Air Quality in Europe 2024 Report.

New Delhi pollution data: Central Pollution Control Board, India. (2024). National Air Quality Index.

2. THE STAKES: WHAT'S BEING LOST

AIR POLLUTION HEALTH IMPACTS: A REGIONAL EMERGENCY

To inform our interventions, we conducted a comprehensive health burden assessment across 20 Brazilian Amazonian cities, revealing a public health emergency.

Mortality Burden Across the Region

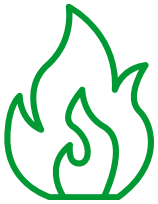
We estimate 9,159 total premature deaths annually are attributable to $PM_{2.5}$ exposure across the Legal Amazon in 2023, ***3,356 (37%) of which are due to air pollution in the 20 largest cities*** in the region. Several Amazon urban centers have recorded mortality rates comparable to some

KEY POINTS

- Air pollution is causing thousands of premature deaths every year in Amazonian cities.
- The economic burden from pollution-related health costs is staggering, reaching hundreds of billions of dollars.
- Vulnerable groups, including Indigenous and low-income communities, are likely to suffer the greatest impacts.
- Pollution rates and health risks are rising faster than population growth.

Top facts

3,356 deaths
due to PM2.5 air pollution in the 20 cities analyzed



15.6 million
hectares of land burned in the Amazon biome in 2024

20-38%
increase in hospitalizations during fire season

More than 40%
share of NOx emissions from transportation in 17 Amazonian cities

industrializing cities in Cali, Colombia (730 $PM_{2.5}$-attributable deaths) and Puebla, Mexico (690 $PM_{2.5}$-attributable deaths). Manaus leads with 944 annual deaths, reflecting both its large population (2.3 million) and severe annual pollution levels (33.3 μg/m^3). Belém follows with 722 deaths annually, while Porto Velho, despite being a smaller city, records 237 deaths due to particularly high annual pollution concentrations (38.3 μg/m^3). Other urban areas where the mortality burden comprises a substantial proportion of the total state burden are Boa Vista (65% of Roraima total), Rio Branco (50% of Acre total), and Macapá (72% of Amapá total) (Figure 3).

Increases in population and air pollution have created concerning temporal trends. From 2000 to 2023, Manaus saw a 173% surge in air pollution-related health deaths (346 to 944; Total population: 2.3 million), while Parauapebas recorded a 477% increase over the same period (13 to 75; Total population 2023: 330,832) (Figure 4). These sharp rises far outpace each city's respective population growth. Population size and growth information for each city is available in Table 3 in the Appendix.

Morbidity Health Impacts:

Although mortality is the most severe outcome, broader health impacts include decreased educational attainment, a lower quality of life due to poor health, and higher healthcare costs for thousands of residents with respiratory and cardiovascular diseases requiring hospitalization, cancer, and pregnancy complications. Peer-reviewed literature indicates that $PM_{2.5}$ exposure in Brazil contributes to increased hospitalizations for heart disease, stroke, and cancer.[14,15,16] Children are particularly vulnerable; evidence suggests that air pollution exposure in Brazil impairs cognitive development and decreases educational test scores.[17] During fire season (typically August–October), $PM_{2.5}$ concentrations can exceed 100 μg/m^3,[18] resulting in poor birth outcomes,[19] an increase in hospitalizations of 20-38%,[20,21] forced school closures, and population migration seeking cleaner air.

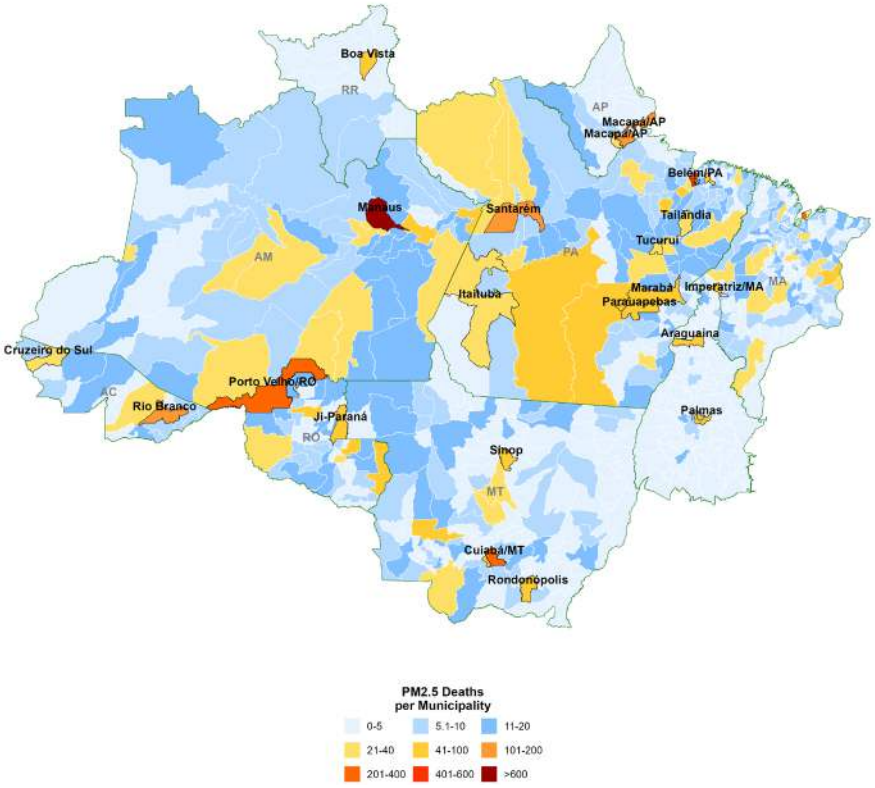


FIGURE 3. $PM_{2.5}$-RELATED MORTALITY IN THE BRAZILIAN AMAZON. TOTAL DEATHS BY MUNICIPALITY (2023).

KEY FINDING

3,356 deaths in 20 largest cities

WHAT THIS MEANS

These urban centers lose more residents to air pollution annually than São Paulo loses to traffic accidents. For comparison, this exceeds the total deaths from dengue fever across all of Brazil in most years.

São Paulo traffic deaths: Companhia de Engenharia de Tráfego (CET-SP). (2024). Acidentes de Trânsito com Vítimas Fatais.

Brazil dengue mortality: Ministry of Health. (2024). Boletim Epidemiológico - Monitoramento dos casos de arboviroses.

ENVIRONMENTAL INJUSTICE: UNEQUAL BURDENS, UNEQUAL ACCESS

In Legal Amazon cities, air pollution reflects and exacerbates deep-rooted social and economic inequalities, reinforcing patterns of inequitable pollution exposure and our analysis confirms these disparities. The Multidimensional Poverty Index (MPI), developed for the Amazon region at the municipal level, measures household deprivation across health, education, and living conditions.[22] Unlike traditional income-based poverty measures, the MPI captures complex, interconnected disadvantages.

Our analysis reveals stark environmental and health inequalities across these 20 Amazonian municipalities. Cities with higher proportions of Indigenous and impoverished populations have higher PM2.5-related mortality rates (Table 3, Appendix). The intersection of environmental injustice and socioeconomic vulnerability is particularly evident in cities such as Boa Vista, which has a relatively high Indigenous population (3.1%) and significant air pollution (16.6 μg/m^3), as well as the highest poverty levels (MPI = 0.155). This results in 304 deaths per 100,000 people. Similarly, Santarém exhibits this pattern, with 27.3 μg/m^3 of PM2.5, an Indigenous population of 0.83%, and significant inequality (MPI = 0.144), resulting in 392 deaths per 100,000 people. In contrast, cities with lower EJ scores, such as Palmas, have substantially lower mortality rates (283 per 100,000 people).

Manaus provides a compelling example of how environmental burdens concentrate in the city's most disadvantaged neighborhoods. Non-favela communities have comparatively cleaner air, with annual average $PM_{2.5}$ concentrations of 32.6 μg/m^3. Meanwhile, 54% of Manaus residents living in favelas[23] breathe air containing 37.1 μg/m^3 of $PM_{2.5}$. While a seemingly small difference, our analysis shows this to be significantly higher statistically than non-favela neighborhoods. This higher exposure compounds the risks presented by poverty and limited healthcare in these neighborhoods.

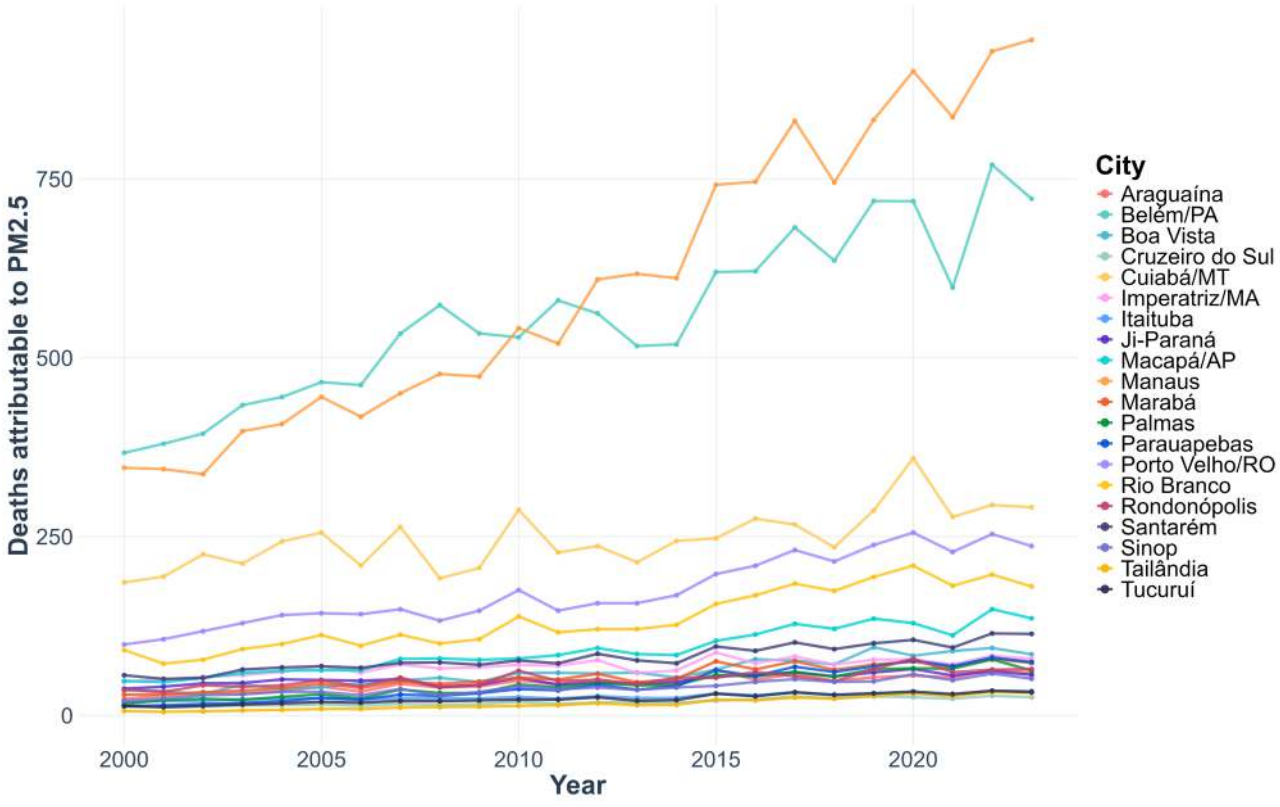


FIGURE 4. TRENDS IN $PM_{2.5}$-ATTRIBUTABLE MORTALITY (N) BETWEEN 2000 AND 2023.

Achieving Brazil's 2025 air quality target of 17 μg/m^3 across Manaus would reduce air pollution mortality risk by approximately 47% (preventing 19 of the current 41 deaths per 100,000 people), while meeting the more ambitious 2044 target of 10 μg/m^3 would reduce mortality risk by 73% (preventing 30 deaths per 100,000 people). Given Manaus's very large informal settlement population (exceeding 50%), a substantial share of the prevented deaths would be concentrated in these communities—typically located near industrial zones, transport hubs, and major traffic corridors.

ECONOMIC COSTS: QUANTIFYING THE DEVELOPMENT BURDEN

To estimate the economic burden of pollution in the region, we applied a Brazil-specific Value of Statistical Life (VSL) approach, using benefit transfer from the 2023 U.S. VSL. Our analysis estimates a cumulative air pollution health economic burden of R$2,185 billion (US$ 437 billion) between 2000 and 2023. The annual burden ranged from 3% to 18% of the local GDP across different cities. Health economic damages exceeded R$500 billion cumulatively in Manaus and Belém between 2000 and 2023 (R$544 billion and R$502 billion, respectively). Since 2000, the cumulative health burden (R$2.18 trillion) has equaled 19% of Brazil's entire 2024 GDP (R$11.7 trillion), which hinders economic development in the region.[24]

Beyond direct mortality costs, evidence from across the globe shows that air pollution generates substantial healthcare expenditures through increased hospital admissions, emergency room visits, pharmaceutical costs, and long-term care for chronic conditions.[25, 26, 27] A recent study analyzing over 2 million hospitalizations in Brazil found that exposure to fire-related air pollution was associated with a 23% increase in respiratory admissions and a 21% increase in circulatory admissions.[28] These estimates are even higher in Brazil's Legal Amazon, where fire related air pollution is associated with a 38% increase in respiratory hospital admissions and 27% increase in circulatory.[29] Wildfires are estimated to impose a cost of up to US$14 million per year in healthcare in Brazil, primarily from increased hospitalizations due to respiratory and cardiovascular diseases.[30] During severe fire seasons, airports often close, river transport can be disrupted, and outdoor economic activities become hazardous, creating cascading economic impacts across supply chains along with direct damages sustained to energy infrastructure (US$130 million), small-scale family farms (US$ 75 million) and biodiversity loss.[17] Another study finds that fires in Acre in 2010 resulted in a total economic loss of US$ 243.36 ± 85.05 million, accounting for ~9% of the state GDP.[31]

KEY FINDING

5% of Manaus GDP annually in health damages

WHAT THIS MEANS

Manaus spends more on air pollution health costs than the city budgets for education and healthcare services combined. This equals the economic output of the city's entire automotive manufacturing sector.

Manaus GDP: IBGE. (2022). PIB dos Municípios 2021. https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/

Manaus municipal budget: Prefeitura de Manaus. (2024). Lei Orçamentária Anual 2024. https://www.manaus.am.gov.br/

Automotive sector output: SUFRAMA. (2023). Indicadores de Desempenho do Polo Industrial de Manaus. https://www.gov.br/suframa/pt-br/

WHAT IS THE CAUSE? SECTORAL EMISSIONS AND UNDERLYING DRIVERS

Air pollution in Amazonian cities represents a convergence of local, medium-range, and long-range transport and transformation of emissions stemming from multiple interconnected sources, reflecting the region's unique development patterns, pressures, and geographic context. Although there has been limited systematic investigation of emission sources in the cities of the Legal Amazon, the few existing studies indicate that fire emissions play a dominant role in seasonal air pollution across the region. Urban anthropogenic emissions, such as those from power plants and vehicles, also contribute to aerosol formation.[32, 33, 34]

To understand the sources of anthropogenic emissions in cities, we used a combination of global and national emissions data sources.[35] The cities of Manaus, Belem, Cuiaba, Porto Velho, Boa Vista, and Rondonópolis contribute the largest total anthropogenic air emissions. Across 13 of the 20 cities evaluated, the industrial energy sector contributed more than 40% of the primary particulate matter emissions. Additionally, the transportation sector was responsible for >40% of NO_x emissions in 17 of the 20 cities (Figure 5). Transportation is a critical sector due to the rapid growth of motorized road and river transportation dependent on fossil fuels without adequate emissions controls. Many Amazonian cities lack vehicle inspection programs, clean fuel standards, and public transit alternatives. This leads to emissions from both passenger and heavy freight traffic due to population growth and the supply chains of the agricultural, extractive, and manufacturing industries.

Residential emissions contributed to more than 10% of primary PM emissions in 90% of the cities evaluated and a dominant source in the cities of Tucurui, Cruzerio do Sul, Tailandia and Macapá, reflecting inequities in energy access within and across cities and the use of solid fuels and diesel to fill cooking, heating, and other energy needs. Smaller cities like Itaituba and Parapuaepebas, with mining-related activities, show high industrial sector emissions (>50% primary PM).

Energy generation contributed significantly to NO_x emissions in Manaus and Boa Vista.[36, 37, 38] In Manaus and most Amazonian cities in this project, over 70-80% of electricity is supplied through Brazil's National Interconnected System (SIN), mainly from hydropower. Natural-gas fired thermoelectric plants in simple-cycle configuration supplement this supply, representing about 10-20% of local generation capacity. Boa Vista (Roraima) remained disconnected from the SIN until 2025, with most electricity generated locally in isolated systems, primarily diesel-fired thermal plants. Small diesel generators in vulnerable urban

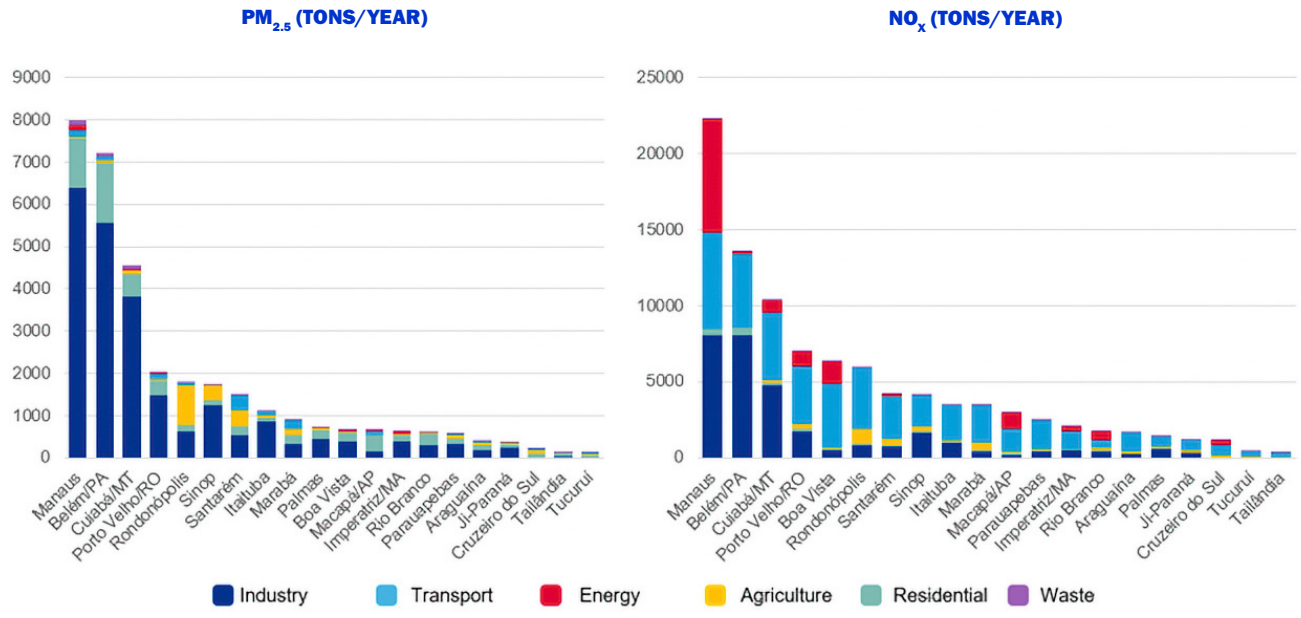


FIGURE 5. DISTRIBUTION OF EMISSION SOURCES BY AMAZONIAN CITY.

communities, though limited in capacity, can still cause significant localized air quality degradation and health risks, especially where high housing density and poor ventilation intensify exposure.

The agricultural sector contributed to emissions in cities such as Rondonopolis, Marabá, Sinop, and Santarem, reflecting the expansion of industrial agriculture for soybean and cattle pasture along the arc of deforestation[39] and the Amazon region.

CLIMATE IMPACTS ON THE LEGAL AMAZON

Cities in the Legal Amazon already face the impacts of climate change, evidenced by record-breaking droughts, wildfires, and extreme heat. In 2024, an estimated 30 million hectares burned across Brazil. Of this total, 15.6 million hectares were in the Amazon biome, meaning that more than half (52%) of all burned areas in the country occurred in the Amazon alone.[40] Periods of drought in the Amazon have resulted in the drying of waterways, creating a public health crisis, isolating communities, and disrupting access to essentials and basic services.[41,42] A recent study of heat waves and mortality in 32 Amazonian cities in Brazil finds there is a 15% and 27% increase in all-cause mortality and higher cardiovascular mortality, respectively, following high-intensity heatwaves.[43] Furthermore, wildfires and heat are known to worsen air pollution-related health outcomes. Under current emission scenarios, heat waves in the region are slated to increase.[44]

Global climate change is intensifying droughts, heat waves, and wildfires in the Amazon. At the same time, emissions from cities—including black carbon, methane, CO_2, and precursors of tropospheric ozone—worsen air quality and contribute to climate forcing. Many of these pollutants originate from the same sources, linking local air pollution with regional and global climate impacts.

Our emission analysis estimates that road transportation contributes 11 million tons of CO_2 per year, while the industrial sector contributes approximately 3.3 million tons per year. Black carbon emissions for the industry, residential, and transport sectors are estimated to contribute 2986, 736, and 653 tons per year, respectively, while methane emissions are dominated by the waste sector, emitting an estimated 71.1 thousand tons of methane per year. Cities in the Legal Amazon face distinct challenges tied to their economic activities and energy systems, which translate into specific emission profiles. Manaus and Boa Vista experience high emissions from power generation. In Rondonópolis, Marabá, Sinop, and Santarém, soybean cultivation, cattle ranching, and deforestation-related burning are the main drivers of agricultural emissions. These challenges reflect the region's unique development pathways, while underscoring opportunities for targeted interventions in key sectors.

KEY FINDING

Only 50% of Amazonas electricity from national grid

WHAT THIS MEANS

Amazonas is Brazil's most energy-isolated state, with diesel dependency 5 times higher than the national average. This makes electricity costs 3-4 times higher than in São Paulo or Rio de Janeiro.

Grid connectivity data: Empresa de Pesquisa Energética (EPE). (2023). Isolated Systems Supply Planning 2024-2028.

Diesel dependency comparison: Agência Nacional de Energia Elétrica (ANEEL). (2024). Sistema de Informações de Geração da ANEEL (SIGA).

Electricity cost comparison: Agência Nacional de Energia Elétrica (ANEEL). (2024). Ranking das Tarifas.

3. HEALTH AND ECONOMIC BENEFITS OF CLEANER AIR

Quantified Mortality Benefits of Reducing Air Pollution

Our analysis shows that achieving Brazil's 2044 target of 10 µg/m^3 annual average $PM_{2.5}$ across all Amazonian cities could prevent approximately **1,280 deaths annually** (a 58% reduction in the current mortality rate) with an estimated avoided health economic burden of R$15.1 billion. The interim 2025 target of 17 µg/m^3 would also generate substantial benefits, preventing an estimated 680 deaths. Achieving the WHO 5 µg/m^3 guideline across all cities could prevent 2,914 of these deaths, representing an 86% reduction in mortality. The benefits would be particularly pronounced in larger urban centers like Manaus, where 896 (95%) out of 945 current deaths could be avoided, and Belém, where 656 (91%) of 723 deaths could be prevented.

KEY POINTS

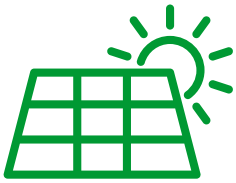
- Meeting Brazil's new air quality standards could save over a thousand lives annually.
- Cleaner air would dramatically reduce healthcare costs.
- Investments in clean air create more jobs than fossil fuel alternatives.
- Targeted interventions can deliver rapid health and climate benefits.
- The greatest gains would likely be felt in the most polluted and disadvantaged communities.

Top facts

58%
fewer deaths by achieving Brazil's 2044 PM2.5 goal

1.5-3x more jobs
generated for every $1 million invested in clean air vs. fossil fuels

33x return
estimated per dollar invested in walking and cycling infrastructure



4x return
estimated per dollar invested in solar PV systems

Economic Gains: Higher Productivity, Lower Health Costs, Business Competitiveness

The economic benefits of air quality improvements extend far beyond avoided healthcare costs to encompass productivity gains, business competitiveness improvements, and enhanced regional economic development. Clean air investments would create substantial employment opportunities across multiple sectors. Studies indicate that clean air investments generate 1.5 to 3 times more jobs for every $1 million invested than their fossil-fuel counterparts[45] and can also help boost energy security in hard-to-reach communities.[46]

Justice Dividends: Reduced Disparities for Marginalized Populations

Cities with the highest environmental justice concerns (Table 3, Appendix) would see the most substantial improvements: Porto Velho could prevent 30 deaths per 100,000 people by reaching the interim target, while Ji-Paraná could avoid 31 deaths per 100,000 people. The greatest marginal benefits would be achieved by focusing efforts on cities with both high current $PM_{2.5}$ concentrations and high environmental justice scores. Moving from current levels to 10 $\mu g/m^3$ would yield 25 prevented deaths per 100,000 people in Itaituba, for instance.

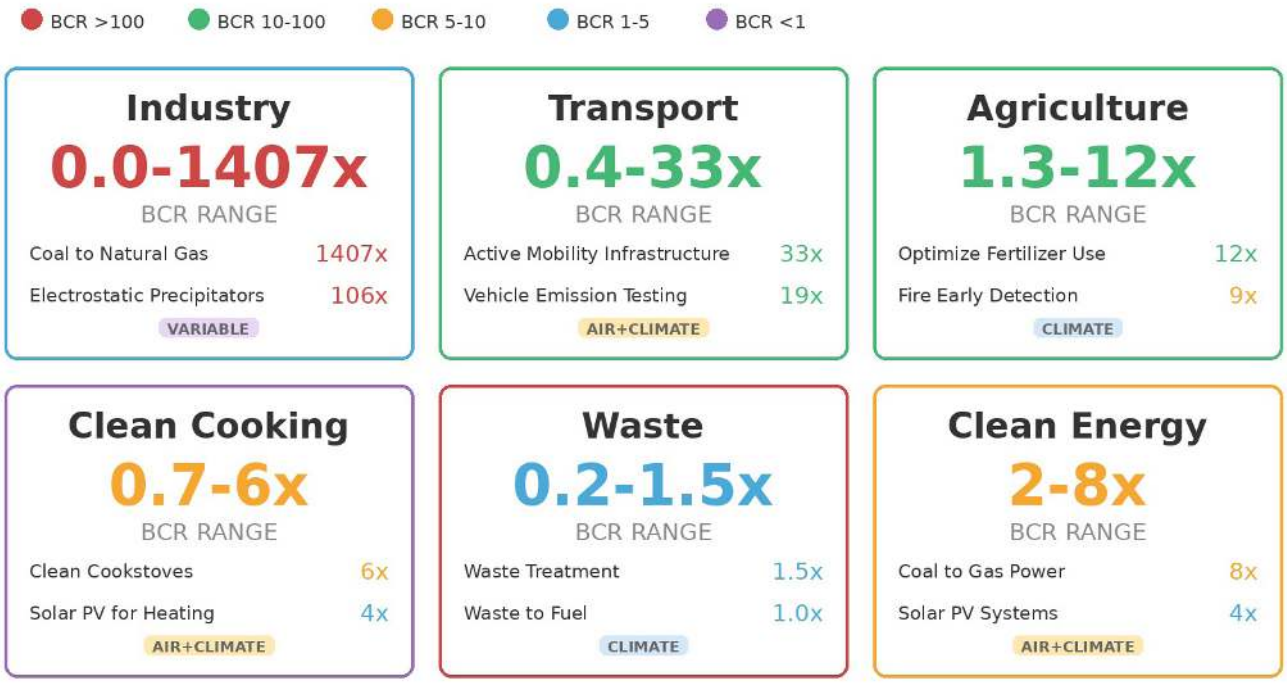


FIGURE 6. BENEFIT COST RATIOS (BCR) FROM 36 CLEAN AIR AND CLIMATE INTERVENTIONS REVIEWED FROM THE GLOBAL SOUTH.69 A BCR HIGHER THAN ONE INDICATES THAT THE BENEFITS ARE GREATER THAN THE COSTS.

PROVEN AND AFFORDABLE CLEAN AIR INTERVENTIONS: COST-EFFECTIVE PATHWAYS TO HEALTH, CLIMATE, AND EQUITY GAINS

Evidence from a review of 36 clean air and climate interventions in the Global South, including contexts such as Brazil, confirms their cost-effectiveness and the breadth of benefits they bring across energy, transport, industry, agriculture, and waste management. Integrated approaches consistently deliver not only cleaner air and reduced greenhouse gas emissions but also improvements in health, resilience, and economic efficiency. Figure 6 demonstrates the benefit-cost ratios (BCR) of the interventions reviewed. A BCR represents the economic return for every dollar invested: a BCR of 10x means that for every $1 spent, $10 in benefits (through avoided health costs, increased productivity, etc.) are generated. A BCR higher than 1 indicates that benefits exceed costs.

The interventions with the largest combined climate and air quality gains include: deployment of clean energy through the transition to variable renewable energy;[47] electrification of public transport fleets;[48] and replacing traditional wood and charcoal cooking with clean alternatives.

Beyond direct health and productivity benefits, clean air investments can also reinforce ongoing regional initiatives in the Amazon that advance governance reforms and sustainable development pathways, including bioeconomy. The World Bank's AM Pro-Sustentabilidade and the IDB/GCF Amazon Bioeconomy Fund are already mobilizing resources for forest protection, fiscal reform, and sustainable value chains. Embedding air quality and health indicators into these programs would ensure that they not only conserve forests and stimulate new markets, but also reduce disease burdens, cut short-lived climate pollutants, and enhance equity across Amazonian cities.

The benefits of cleaner air are clear, but realizing them depends on embedding air quality into governance, development, and finance. The next section outlines the enabling conditions needed to overcome barriers and translate these benefits into lasting impact for Amazonian cities.

4. ENABLING CONDITIONS FOR ACTION

Achieving the health, economic, climate, and equity gains highlighted in this report will only be possible if proven, high-impact solutions are scaled and implemented without delay. This requires:

- Decisive action from all levels of government—local, state, and national.
- Strong coordination across institutions and sectors.
- Inclusive engagement with communities, civil society, and the private sector.
- Sustained domestic and international funding to close critical capacity and financing gaps.

KEY POINTS

- Policy gaps, weak enforcement, and limited funding hinder progress on clean air.
- Air quality monitoring is sparse and needs expansion to cover more pollutants.
- Stronger coordination between federal, state, and local governments is essential.
- Mobilizing development banks, donors, and private investors can unlock large-scale solutions.
- Closing institutional and financial gaps will enable transformative investments.

Top facts

2024
the year Brazil's new air quality law and tighter standards took effect

0
number of reference-grade air quality monitoring stations in the Brazilian Amazon

$1 billion+ USD
Size of large-scale multilateral funds focused on Amazon region sustainability

Almost no
dedicated air quality officers in majority of the 20 cities analyzed

Amazonian cities—on the frontline of exposure—face persistent deficits in policy implementation, monitoring, financing, and institutional capacity that limit their response.

Closing these gaps is more than removing barriers—it is an opportunity to align governments, development banks, donors, private investors, and international partners around a shared agenda. This section highlights where barriers lie and how addressing them can unlock transformative investment and lasting impact across the Amazon.

Policy Gaps

Brazil's National Air Quality Policy Law (Law No. 14,850/2024) and updated National Air Quality Standards under CONAMA Resolution 506/2024, both adopted in 2024, mark an important step toward modernizing the country's regulatory framework. Together, they establish binding numerical targets for key pollutants, mandate standardized monitoring through the new MonitorAr[49] program, and create mechanisms for federal, state, and municipal coordination. The standards adopted interim targets that move progressively toward WHO Air Quality Guidelines.

Institutional capacity and coordination challenges remain acute. Federal agencies such as IBAMA and the Ministry of the Environment set national policy but have limited resources for on-the-ground implementation. State environmental agencies in the Legal Amazon often operate with fewer than 50 technical staff across vast territories, while most municipal governments lack even a single dedicated air quality officer.

Gaps in Air Quality Monitoring

Air quality monitoring in the Legal Amazon remains sparse, fragmented and primarily focused on $PM_{2.5}$, leaving significant gaps for other pollutants with major health and climate impacts. There are currently no regulatory (reference-grade) monitoring stations operating in the Brazilian Amazon, and most measurements rely on university-led or subnational sensor networks with varying quality assurance levels. Systematic measurement of ground-level ozone, NO_2, SO_2, and volatile organic compounds (VOCs) is rare, limiting the ability to track these health-harming pollutants and climate relevant pollutants, many of which also drive secondary PM formation. Despite the Amazon's emissions of black carbon (BC) from biomass burning and diesel, BC monitoring is restricted to a few research sites. Methane and other potent climate forcers are largely absent from air monitoring programs.

Economic Incentive Gaps

Tax policies, procurement practices, and licensing processes rarely recognize or reward voluntary air quality improvements beyond minimum compliance. Access to green financing is scarce, with most banks lacking the capacity to assess air quality projects or provide technical guidance for the adoption of clean technology. While international climate finance is available, its complex application procedures and demanding technical requirements often exceed the capacity of local businesses.

ALIGNING INSTITUTIONS, INVESTORS, AND FUNDING FOR CLEAN AIR ACTION

Delivering clean air investments in Amazonian cities requires not only strengthening federal, state, and municipal institutions, but also mobilizing multilateral development banks (MDBs), national development banks, donors, and private investors to move beyond diagnostics toward scaled and sustained investment. In particular, MDBs can play a catalytic role by aligning financing with national and local priorities and building the institutional capacity needed to translate resources into lasting impact.

The most effective strategic entry point is the co-benefits approach: framing clean air as an integrated investment in health, climate, and equity, because this perspective unlocks broader political will, attracts diverse financing streams, and ensures that interventions deliver multiple, measurable returns beyond air quality alone. This framing creates alignment across MDB portfolios (including urban resilience, health,

energy transition, and climate adaptation) as well as and across MDBs themselves, ensuring that institutions like the Development Bank of Latin America and the Caribbean (CAF) and Inter-American Development Bank (IDB) build on each other's investments and work toward shared clean air co-benefits, while also aligning with donor priorities and private investors' ESG mandates. Anchoring investments in Brazil's updated air quality standards (CONAMA 506/2024) and COP30 momentum provides both credibility and urgency.

Building on this foundation, the following set of opportunities outline how ambition can be translated into concrete, scalable action.

1. Aligning Institutions with Funding Streams

The alignment of institutions, investors, and funding streams is central to scaling clean air action in Amazonian cities.

- Leverage federal expertise to lead large-scale infrastructure and monitoring programs.
- Enable state governments to scale interventions (e.g. fleet electrification, early-warning systems for fires) through state development banks like BNDES (National Bank for Economic and Social Development) and BASA (Bank of the Amazon).
- Strengthen municipalities with dedicated capacity-building and long-term funding for transport, waste, and urban planning.
- Harness civil society and academia to expand low-cost monitoring, citizen science, and awareness campaigns.
- Support SMEs (Small and medium-sized enterprises) to overcome technical and financial barriers in adopting clean technologies.

2. Strengthening Local Capacity

- Investments in people and institutions unlock the design and delivery of bankable clean air projects.
- Establish municipal air quality units, train officials, and create project preparation facilities.
- Integrate air quality metrics into urban mobility, waste, and health planning at subnational levels.
- Expand monitoring and early warning systems, targeting vulnerable communities, schools, and clinics with low-cost sensors, satellite data, and public alerts.

3. Innovating Finance and Leveraging MDBs

MDBs and national banks can bridge the gap between institutional capacity and scalable finance.

- Integrate clean air and health indicators into existing large-scale programs, such as the World Bank's Amazon Pro-Sustentabilidade (US$592M) and the IDB/GCF Amazon Bioeconomy Fund (US$598M), so that governance reforms and bioeconomy value chains not only mobilize billions but also deliver greater health, climate and equity benefits through embedded clean air targets in their design and monitoring frameworks.
- Expand facilities (e.g., IDB's Emerging and Sustainable Cities Program, CAF's Ciudades con Futuro) to move Amazonian municipalities from planning to investment readiness, with the technical, institutional, and financial capacity to attract and manage funding.
- Designing blended instruments that combine concessional finance, guarantees, and results-based payments (SMEs credit guarantees, fleet electrification risk sharing).
- Link disbursements to results, such as $PM_{2.5}$ reductions, compliance with CONAMA 506/2024) or expanded monitoring coverage.
- Support subnational bonds, tied to pollution reduction and health outcomes.

4. Catalyzing Action Through Donnor Support

Multilateral, bilateral, and philanthropic donors can unlock early-stage and equity-focused interventions:

- Finance critical gaps in monitoring infrastructure, institutional strengthening, and pilot interventions such as low-emission transport corridors, clean cooking solutions, waste management pilots, or community-based fire prevention programs.

- Support innovation with equity, such as clean air shelters, citizen platforms, and community-driven fire management.
- Strengthen engagement with urban grassroots and vulnerable groups, while recognizing Indigenous communities present in Amazon cities, to ensure interventions are inclusive and locally grounded.

5. Mobilizing Private Capital for Scale

Private capital can bring both scale and innovation when paired with public and concessional finance:

- Attract impact investors and ESG funds by channeling capital into clean mobility, renewable energy, and green logistics projects that demonstrate clear, measurable health and climate co-benefits.
- Engage corporations through sustainability-linked loans and transition bonds tied to emissions reductions.
- Scale PPPs (public–private partnerships) in waste management, mobility, and industrial retrofits with MDB or donor-backed guarantees.
- Support startups for venture capital and green accelerators for monitoring, fire management technologies, and distributed energy solutions.
- Channel capital via blended finance, including the Amazon Bioeconomy Fund's, to de-risk investments in sustainable value chains such as agroforestry, aquaculture, bio-based industries and ecotourism.

5. MANAUS: A CASE STUDY

This section presents findings from an in-depth case study of Manaus, conducted through desk research, spatial analysis, and direct stakeholder engagement including a workshop with government officials, researchers, and civil society representatives in the Summer of 2025.

MANAUS: AN ECONOMIC HUB WITH SIGNIFICANT AIR QUALITY CHALLENGES

Manaus stands at the crossroads of Amazonian's natural wealth (Figure 7) and the pressures of urban development. The capital of the state of Amazonas, it is the largest metropolitan area in the region. With 2.3 million residents, and a GDP of R$103.2 billion in 2021, Manaus is the Amazon's economic and political powerhouse.

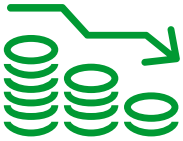
KEY POINTS

- Manaus is an economic powerhouse but also an air pollution hotspot.
- Industrial emissions, old diesel vehicles, and local energy generation drive high pollution levels.
- Health costs from air pollution equal a significant share of the city's GDP.
- Despite existing policies, Manaus lacks a comprehensive air quality management plan.
- The city has unique opportunities to lead on clean mobility, renewable energy, and bioeconomy innovation.

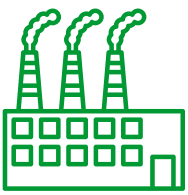
Top facts

Nearly 7x
Amount by which Manaus' avg. annual PM2.5 exceeds WHO guideline

3x increase
in number of motor vehicles in Manaus since 2010



5% of GDP lost
In health-related economic damages due to air pollution in Manaus



80 percent
industry's contribution to primary PM2.5 in Manaus

Historically shaped by the rubber boom (1879-1912) and the Zona Franca industrial model (established 1967), Manaus now faces worsening air quality, escalating climate risks, and structural inequality. At the same time, new financial and policy commitments, including bioeconomy initiatives, are emerging to support a more sustainable, inclusive, low-carbon trajectory for the Amazon.

Pollution and Health Burden: Among the Highest in Brazil

The air in Manaus is far from clean. Annual $PM_{2.5}$ concentrations average 33.3 μg/m³, nearly seven times the WHO's guideline. This translates to 944 premature deaths each year and R$7 billion (USD $1.4 billion) in annual health-related economic damages, equivalent to 5% of the city's GDP. Since 2000, mortality linked to air pollution has climbed by 173%, a stark signal of rapid urban expansion further compounded by increasingly intense and frequent fire seasons.

Local Sources and Regional Pressures

The sources of this pollution are complex and interconnected. The Free Trade Zone (ZFM), is the heart of Manaus's industrial economy and produces electronics, automobiles, plastics, food products, and heavy machinery. These activities generate NO_x, volatile organic compounds, and particulates from manufacturing processes, on-site energy generation, and supply chain transport. Environmental licensing exists, but enforcement is limited, and many facilities still operate without modern emissions controls. Energy needs drive large combustion emissions: industry contributes 36% of NO_x and 80% of primary $PM_{2.5}$, while transportation accounts for 29% of NO_x, electricity generation for 33%, and residential combustion for 15% of $PM_{2.5}$ (Figure 8).

The city's motor vehicle fleet has tripled since 2010, now surpassing 950,000 vehicles, one-quarter of them two-wheelers,[50] with public transport dominated by aging diesel buses lacking emissions controls. Riverine transport connects communities and moves goods efficiently, but almost entirely on diesel and fuel oil. Only half of the state's electricity comes from the national grid; the rest is generated locally in isolated systems running on fuel oil, diesel, and natural gas, supplemented by countless backup generators in industry. Studies confirm stationary sources are major contributors to the city's air pollution.[51] Adding to these local pressures are regional forces beyond the city's direct control. Seasonal agricultural and forest fires can push $PM_{2.5}$ above 100 μg/m³.

Opportunities for Emissions Reduction and Cleaner Technologies

Manaus holds strategic advantages for advancing clean air and sustainable growth.

- The Free Trade Zone administration (SUFRAMA) can engage manufacturers to adopt clean production, emissions monitoring, and renewable energy.
- Despite state incentives (the State Policy to Encourage the Use of Renewable Energy Sources and Energy Efficiency), the state of Amazonas has among the lowest solar energy uptake.[52] Public-private partnerships in the ZFM could accelerate solar PV deployment.[53]
- As Brazil's two-wheeler hub, Manaus could lead electric motorcycle (e-moto) production, supplying domestic and export markets while cutting urban emissions. The MOVER program (Programa Mobilidade Verde e Inovação)[54] provides regulatory and financial leverage for this shift.
- Expand clean mobility options through electric and hybrid buses, enhanced BRT corridors, cycling networks, and pedestrian-friendly infrastructure to reduce congestion and air pollution. Integrating urban freight solutions such as cargo consolidation centers and low-emission delivery systems will also improve efficiency and lower costs.
- Modernizing medium and large riverboats with pollution controls, hybrid or solar-electric systems would reduce emissions while improving connectivity and social inclusion
- Retrofitting natural-gas plants with low-NO burners or SCR systems can cut emissions by up to 90% at about US $40–100 per kW. Over time, combined-cycle upgrades or solar-battery hybrids could further reduce fuel use and pollution.

New bioeconomy opportunities further expand this horizon. Manaus is taking steps to position itself as a hub for sustainable bio-based value chains, leveraging its industrial base, tax-incentive zone, research institutions (such as INPA and the Amazon Biotechnology Center) and proximity to Amazon biodiversity. Opportunities include sustainable açaí production and other agroforestry products, aquaculture, ecotourism, and biopharmaceuticals. This direction aligns with multilateral efforts such as the World Bank's AM Pro-Sustainability program, which explicitly aims to stimulate bioeconomy enterprises and governance reforms in Amazonas[55] and the GCF/IDB Amazon Bioeconomy Fund, which mobilizes resources for forest-based and nature-based sectors across Amazon countries.[56] IDB Lab's new bioeconomy initiatives in the Amazon further underscore the region's innovation potential.[57]

Clean air is a missing but critical dimension in MDB Amazon programs. Integrating clean air goals into these initiatives can create synergies because cleaner production methods, reduced burning, and low-emission transport not only improve local air quality but also strengthen the sustainability credentials and market value of these products. Healthier air supports community well-being and workforce productivity, while

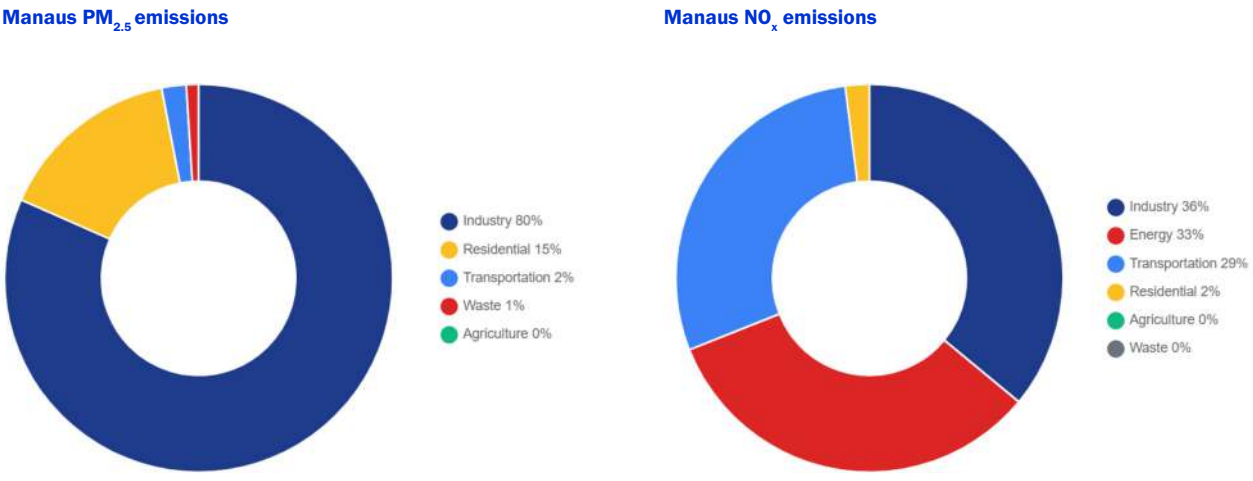


FIGURE 8. THE MAIN LOCAL SOURCES IN MANAUS: INDUSTRY, TRANSPORT, ENERGY, BIOMASS BURNING.

climate resilience benefits via reduced deforestation, sustainable land use, and renewable energy deployment.

In turn, a thriving, well-designed bioeconomy could generate new revenue streams and local jobs that help finance and sustain clean air interventions—creating a virtuous cycle in which economic growth, environmental protection, and public health reinforce one another, enhancing Manaus's appeal to global partners interested in both conservation and innovation. Recent IDB initiatives, such as Bioeconomy Ecosystem Hubs[58] and Amazon Journey,[59] also underscore Manaus's potential serve as a regional hub where innovation, clean air, and sustainable development converge.

Currently, Manaus lacks reference-grade air quality monitoring stations, relying instead on limited university-operated sensor networks. To put existing policy ambitions into practice, Manaus needs a reference-grade multipollutant monitoring network, complemented by a network of calibrated low-cost sensors, coupled to an integrated, regional air quality monitoring and early alert system. This system would track compliance with national standards, reveal exposure disparities, and measure progress, providing the data needed to target and evaluate interventions.

Policy and Institutional Framework

As the state capital and a hub for federal agencies, Manaus has the political reach to advance more robust policies:

- Its research institutions include the Federal University of Amazonas (UFAM) and the National Institute for Amazon Research (INPA), while SUFRAMA offers a strategic channel to engage the industry in adopting cleaner production practices.
- It has an advanced municipal governance structure. Key institutions include SEMMAS (Municipal Secretariat for Environment and Sustainability), for environmental conservation, licensing, and compliance with environmental regulations;[60] IMPLURB (Municipal Urban Planning Institute) for land use and zoning regulations;[61] IMMU (Municipal Urban Mobility Institute)—responsible for managing traffic, transport infrastructure, and implementing mobility plans that can support cleaner transport alternatives, as well as assisting federal and state entities in monitoring vehicular emissions;[62] SEMSA (Municipal Secretariat of Health), leads local health policy and has the competence for monitoring and responding to pollution-related health outcomes through environmental surveillance.[63]
- Manaus is among the few Amazonian cities with an explicit environmental legal framework. It has adopted a Municipal Environmental Code,[64] a Municipal Climate Policy,[65] and an Urban Mobility Plan.[66] These frameworks provide a basis for action but remain disconnected from a systematic air quality management approach.
- Despite the presence of relevant institutions and policies, Manaus lacks a dedicated municipal air quality plan, emission inventory, or monitoring strategy, and there are no comprehensive air monitoring programs at the local level.[67]

Conclusion

Manaus illustrates both the risks of unchecked industrial-urban growth and the opportunities of aligning bioeconomy strategies with clean air action. With the right policies, monitoring infrastructure, and investment pathways, the city can transition from being a pollution hotspot to a model for inclusive, low-carbon development in the Amazon.

KEY FINDING 55% increase in PM2.5 in Manaus since 2000

WHAT THIS MEANS Air pollution is worsening 5 times faster than the city's population growth.

Population growth data: IBGE. (2022). Census 2022: Historical Population Trends by Municipality.

Pollution vs population growth ratio: 55% pollution increase ÷ 11% per capita pollution increase (accounting for population growth) ≈ 5x faster

6. TOWARDS A ROADMAP FOR CLEAN AIR IN AMAZON CITIES

The pathway to cleaner air in Amazonian cities must be grounded in Brazil's evolving policy frameworks, including the National Policy on Air Quality, the updated CONAMA Resolution 491/2018 with progressive $PM_{2.5}$ standards through 2044, the National Climate Change Policy, and the forthcoming 20-Year National Air Quality Plan. These frameworks establish compliance timelines, reporting obligations, and instruments such as the National Air Quality Information System and State and Municipal Plans.

Investments must be aligned with financing cycles and synchronized with federal and state budgets, the Amazon Fund, and MDB operations such as the World Bank's AM Pro-Sustentabilidade and the IDB/GCF Amazon Bioeconomy Fund, to ensure projects can move from planning to disbursement within 12 to 24 months. They must also be connected to international commitments, including Brazil's NDC under the Paris Agreement, the Global Methane Pledge, and the Sustainable Development Goals, which create entry points for co-financing and recognition of air quality improvements as climate and health achievements. Brazil's hosting of COP30 in Belém will bring global attention to Amazon sustainability, creating a moment to showcase specific measures that unite clean air, climate, health, equity, and economic opportunity.

This transformation requires a coalition in which: federal, state, and municipal governments share leadership; the private sector commits to cleaner practices; and civil society, including Coalizão Respira Amazônia and academic partners such as Fiocruz and IMPA, ensures oversight and inclusion.

KEY POINTS

- Brazil's evolving policy frameworks set the stage for ambitious clean air action.
- Investments should align with major funding sources and leverage international climate finance.
- COP30 in Belém is a chance to showcase integrated solutions for health, climate, and equity.
- Priority interventions include industrial controls, clean transport, renewable energy, and regional monitoring systems.
- Cleaner air is the key to unlocking health, prosperity, and climate resilience for Amazonian cities.

This report can serve as a high-profile moment to:

- Build a shared understanding of the health, climate, equity, and economic case for investing in clean air in Amazonian cities, grounded in the evidence presented here, to guide priority interventions and inform future financing opportunities.
- Maintain conversations on advancing clean air, health, climate, and equity in Amazon cities through existing networks and coalitions by:
  - Raising awareness of air pollution's levels, sources and impacts, and the benefits of cleaner air.
  - Developing priority interventions and sharing emerging plans to inform financing opportunities.

- Connecting with regional initiatives and engaging the private sector to link clean air, climate, and inclusive development.

CONCRETE PRIORITY INTERVENTIONS

The following preliminary list of high-impact priority investments for Amazon Cities (Table 1) stems from this project's scientific analysis of air pollution, emission sources, and impacts, as well as consultations with key stakeholders, including a regional virtual workshop, in-person discussions in Manaus, and targeted interviews and meetings.

Presented for illustrative purposes only, this table does not prescribe specific actions or scales of intervention, but rather illustrates the magnitude of opportunities and the level of ambition required. Cost ranges are indicative, drawing on international benchmarks and conservative adjustments for Amazon-specific conditions. The list highlights interventions across major emission sources—industrial controls, urban and river transport, and energy access—together with cross-cutting measures such as a Regional Air Quality Monitoring and Early-Warning System in the Amazon Region. Collectively, these proposals point to scalable investments that can deliver cleaner air and maximize health, climate, equity, and economic co-benefits while reinforcing sustainable development pathways in the region.

These proposed investments are intended to inform a future multi-donor, multi-investor regional initiative aligned with federal, state and municipal air quality and climate plans. Clean air investments should prioritize sectors that deliver the fastest and most visible health, climate, equity, and economic co-benefits, while creating synergies with dynamic areas such as bioeconomy, sustainable tourism, and regenerative agriculture.

For example, embedding air quality, health and equity indicators into major investments, such as the World Bank's AM Pro-Sustentabilidade (US$592.5M) and the IDB/GCF Amazon Bioeconomy Fund (US$598M), would multiply returns, safeguard against unintended impacts, and help ensure that development prompted by these emerging drivers is fully compatible with clean air, health, and climate goals for all.

AMAZON REGION AIR QUALITY MONITORING AND EARLY-WARNING SYSTEM

Special mention should be made of the opportunity to invest in the development of a regionwide, integrated and coordinated Air Quality Monitoring and Early-Warning System for the Legal Amazon, identified through technical analysis and stakeholder consultations as a priority cross-cutting action to enable clean air efforts across the region. Effective monitoring is the backbone of smart investments: it ensures accountability, guides enforcement, and proves health and climate gains. In the Amazonian context, a region-wide, integrated and coordinated regional system is essential, moving beyond fragmented, city-by-city initiatives toward a shared platform that reflects the ecological and transboundary realities of the region. When integrated with early-warning systems and heath surveillance systems, it also provides timely alerts on fires, pollution peaks, and health risks—protecting communities and enabling performance-based finance.

This system should also be anchored in the development of:

- **Regional emission inventories, atmospheric models, and analytical tools** capable of pinpointing sources and hotspots in near real-time, allowing authorities to distinguish between fire-related, transport, industrial, and waste-burning emissions, improving both policy design and enforcement.
- **Integration with national systems**, including MonitorAr, INPE Queimadas[68], MapBiomas Fogo, and Vigiar, a program under the Unified Health System (SUS, Sistema Único de Saúde), so that air pollution, fire, weather, and health data are merged into a unified early-warning and response platform.
- **Institutional partnerships** with IMPA, Fiocruz, INPA, and federal and state universities to ensure scientific credibility, public health relevance, and operational sustainability.

TABLE 1. PRELIMINARY CLEAN AIR INVESTMENTS FOR AMAZON CITIES: CLEAN AIR ACTIONS WITH CO-BENEFITS FOR HEALTH, CLIMATE, EQUITY, AND ECONOMY

PRIORITY AREA	PROPOSED INTERVENTION	SCALE AND COST	POTENTIAL PARTNERS
Industrial emissions	Install advanced controls (filters, scrubbers, SCR) and Continuous Emissions Monitoring Systems (CEMS) in priority factories in the Manaus Free Trade Zone and in Pará's industrial/mining hubs.	~US$ 50–70M (phased)	SUFRAMA, state env. agencies, WB/IFC, private sector
Bioeconomy and innovation	Launch "Clean Air–Positive Bioeconomy Zones" (zero-burning, renewable energy, clean logistics for agroforestry, açaí, aquaculture and forest products) in 2 pilot regions	~US$ 60–80M	IDB/GCF Amazon Bioeconomy Fund, Centro de Bionegócios, private investors
Urban transport (land)	Deploy 200 battery-electric buses in Belém and Manaus, with depots and chargers; prepare expansion projects for +500 by 2027	~US$ 110–135M	CAF/IDB, municipalities
River and port transport (large ships and freight)	Transition passenger and freight fleets to low- and zero-emission propulsion (electric–hybrid ferries, LNG/hydrogen pilots) and install shore power in major ports (Manaus, Belém, Santarém, Santarém)	~US$ 150–200M (first wave)	PAC Mobilidade, WB, IDB, CAF, port authorities, private shipping
Cross-sector: Regionwide monitoring and early-warning	Establish a Regional Air Quality Monitoring and Early-Warning System with regulatory stations, low-cost sensors in high-exposure sites, and QA/QC hubs integrated with MonitorAr, INPE Queimadas, MapBiomas Fogo, Fiocruz, SUS, and state agencies.	~US$ 12–15M + O&M	MMA, Fiocruz, IMPA, universities, philanthropy
Cross-sector: fire & land use	Expand community fire brigades and PES pilots in Pará & Amazonas, linked to city-level AQ alerts and enforcement	~US$ 20–25M	Amazon Fund, GIZ, USAID, ICMBio, state civil defense

SCR: Selective Catalytic Reduction; CEMS: Continuous Emissions Monitoring Systems; SUFRAMA: Superintendência da Zona Franca de Manaus (Manaus Free Trade Zone Superintendency); WB: World Bank; IFC: International Finance Corporation; IDB: Inter-American Development Bank; GCF: Green Climate Fund; CAF: Development Bank of Latin America; LNG: Liquefied Natural Gas; PAC: Programa de Aceleração do Crescimento (Growth Acceleration Program); BNDES: Banco Nacional de Desenvolvimento Econômico e Social (Brazilian Development Bank); ESCOs: Energy Service Companies; QA/QC: Quality Assurance/Quality Control; INPE: Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research); SUS: Sistema **Único** de Saúde (Unified Health System); Fiocruz: Fundação Oswaldo Cruz (Oswaldo Cruz Foundation); IMPA: Instituto de Matemática Pura e Aplicada (Institute for Pure and Applied Mathematics); MMA: Ministério do Meio Ambiente (Ministry of the Environment); O&M: Operations and Maintenance; PES: Payment for Environmental Services; GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation); USAID: United States Agency for International Development; ICMBio: Instituto Chico Mendes de Conservação da Biodiversidade (Chico Mendes Institute for Biodiversity Conservation); AQ: Air Quality

Network Design

- **Regulatory (reference-grade) monitoring stations:** Each medium-sized city (100,000–500,000 inhabitants) should host at least one regulatory station; larger cities (Manaus, Belém, São Luís) should operate three to five stations strategically distributed across compliance, hotspot/source-oriented, population exposure, background, and research sites.
- **Key pollutants and parameters to be measured:** $PM_{2.5}$, PM_{10}, ozone, NO_2, CO, SO_2, BC, and VOCs where relevant. Meteorological parameters (temperature, humidity, wind speed/direction, precipitation, solar radiation) are also critical to interpret pollution patterns and model transport.
- **Calibrated low-cost sensor networks:** Calibrated low-cost sensors showing representative concentrations across cities, with a focus on high-exposure and community settings such as schools, health facilities, transport corridors, ports, and fire-prone areas. This complements reference-grade data, expands coverage cost-effectively, and enhances near–real-time hotspot detection.
- **Regional QA/QC, training, and calibration hubs:** Shared regional hubs for quality assurance/quality control, calibration, training, and data management—reducing municipal burdens, ensuring comparability across cities, and building long-term capacity for operation and maintenance.

ESTIMATED COSTS

The following cost ranges are derived from international benchmark sources and current market values. Combining federal and state budgets, multilateral development banks, philanthropy, and private sector contributions (e.g., corporate social responsibility) through blended finance will be essential to sustain the system and prepare it for performance-based mechanisms.

- Regulatory (reference-grade) stations:
  - Individual equipment for core criteria pollutants and meteorology totals approximately US$ 240 000–270 000, including analyzers for $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO, calibration systems, datalogger, and meteorological tower.
  - With site installation (power, climate control, fencing), the complete installed cost averages US$ 260 000–300 000 per station.
  - However, by adopting modular configurations, enabling local assembly of shelters and system components, and employing selective instrumentation, such as multipollutant or hybrid analyzers focused on priority pollutants (e.g., $PM_{2.5}$, O_3, and NO_2), optimized regulatory-grade stations can realistically range between US$ 120,000 and US$ 180,000. This range represents a realistic lower bound for well-designed, locally adapted installations in Amazon-region cities.
  - Annual operations and maintenance per station: approximately US$ 8 000–12 000 depending on logistics, calibration frequency, and staffing.

- Low-cost sensor units:
  - US$ 400–2 000 per unit, depending on sensor type, housing, connectivity, and calibration requirements.
  - Annual operations and maintenance: roughly US$ 200–400 for recalibration, data management, and replacement cycles.

- Regional QA/QC hubs:
  - US$ 400 000–600 000 per hub (including calibration labs, training facilities, data servers, and staff).

- Estimated total investment for a 10-city integrated regional network:
  - Assuming ~25 reference-grade stations and ~250 low-cost sensors, the aggregate investment is approximately US$ 10–14 million, plus ~US$ 1–1.5 million/year for operations and maintenance.

EXISTING FOUNDATIONS AND SYNERGIES

Several initiatives already provide strong foundations to build an integrated clean air and health agenda for Amazonian cities, as shown in Table 2. In monitoring and early warning, the federal *MonitorAr* program, Fiocruz, INPA, IMPA, and state agencies are building a strong regional base, complemented by *MapBiomas Fogo* and INPE's *Queimadas* system for fire detection. The Coalizão Respira Amazônia reinforces this ecosystem with over 180 low-cost sensors across the Legal Amazon, generating open data and linking citizen monitoring with Fiocruz's new Air Quality and Health Surveillance system. In parallel, the Fundação Amazônia Sustentável (FAS) is advancing solar electrification and community-based energy solutions that cut diesel use and improve health. Alongside broader efforts in transport innovation, waste management, green industry, and major multilateral financing programs, these initiatives show that the technical, social, and financial pillars are already aligning to embed clean air and health into the Amazon's development trajectory.

A CALL TO ACTION

The future of the Amazon depends largely on what happens in its cities. Building on the shared vision outlined in this report, Brazil can advance a coordinated set of clean air investments, endorsed by governments, financed by development banks and climate funds, and co-owned by communities and businesses. This is not only an environmental imperative, but also a health, climate, equity, and economic opportunity of global relevance.

The promise is clear:

- Thousands of lives saved each year through reduced exposure to $PM_{2.5}$ and toxic pollutants.
- Billions unlocked in economic value by cutting health costs, boosting labor productivity, and enabling sustainable industries.
- Rapid reductions in climate pollutants, including methane, black carbon, and other SLCPs, accelerating progress towards Brazil's NDC and global climate targets.
- Justice and dignity restored to vulnerable and marginalized populations disproportionately burdened by pollution.

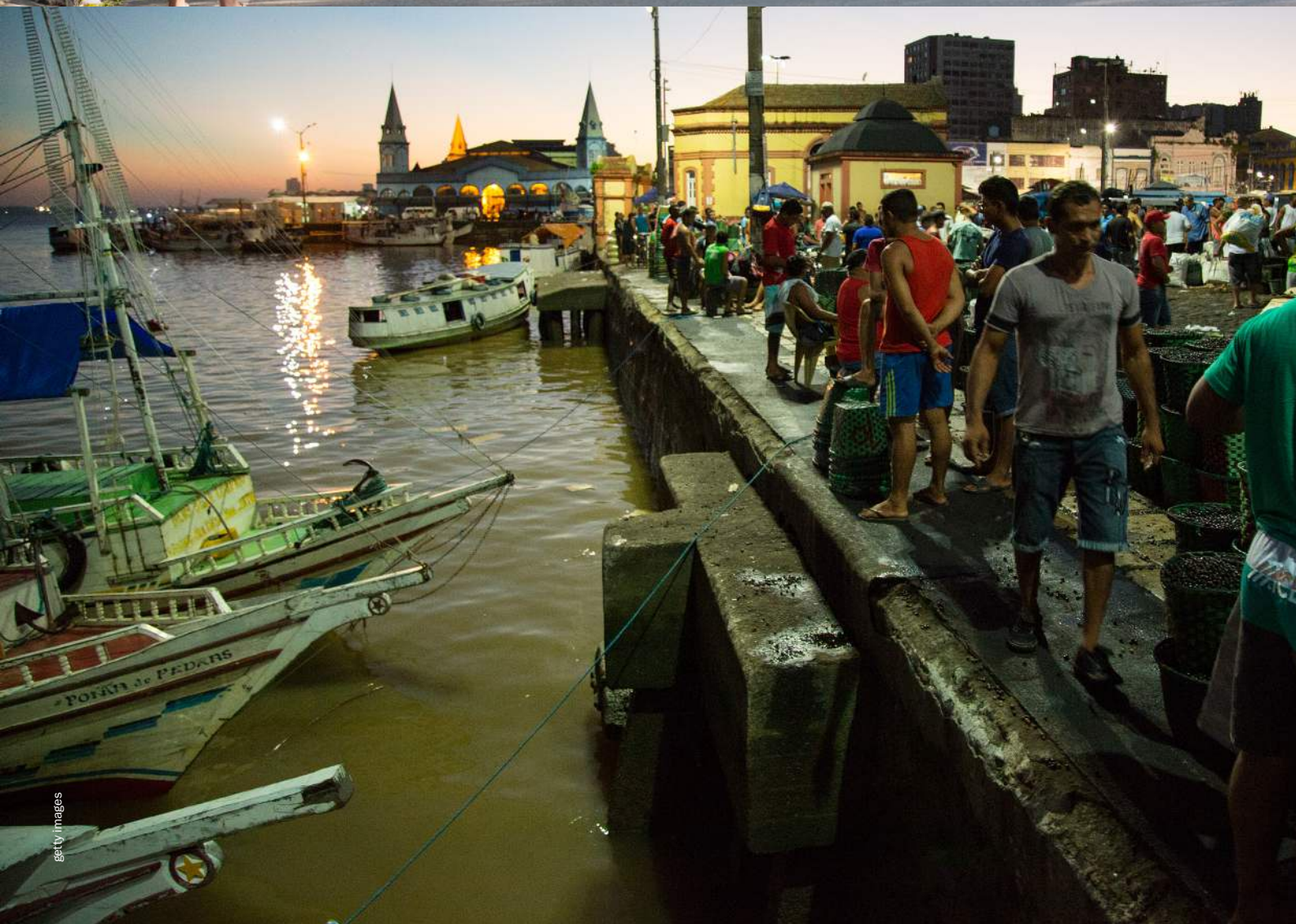
To seize this promise, coordinated action across Amazonian cities — involving federal, state, and municipal governments, civil society, communities, and the private sector — is needed to:

- Prioritize high-impact, multi-benefit investments that directly target the main pollution sources, from transport and fossil-fueled power generation to waste burning and illegal fires.
- Coordinate across federal, state, and municipal levels, sharing leadership and aligning with national clean-air policies and standards.
- Advance monitoring and transparency by deploying regional networks, strengthening emission inventories, and integrating ground-based and satellite data.
- Secure co-financing from subnational and national budgets, complemented by international partners, investors, and climate funds, to support sustainable urban development and inclusive economic growth.
- Align clean air investments with climate action, and sustainable economic transformation, ensuring that air quality actions deliver co-benefits.

Cleaner air is the bridge that unites health, climate, equity, and prosperity. ***For Amazonian cities, the time to act for clean air, and to breathe freely, is now.***

TABLE 2. CURRENT AND ONGOING INITIATIVES TO ACHIEVE CLEANER AIR IN AMAZONIAN CITIES

TYPE	CURRENT INITIATIVES
Monitoring and early warning systems	Coalizão Respira Amazônia is expanding air quality monitoring in the Amazon Legal with over 180 low-cost sensors, providing open data to support science, policy, and community awareness on pollution and health.
	The federal MonitorAr program, IMPA (Institute for Pure and Applied Mathematics) projects, Fiocruz (Oswaldo Cruz Foundation), and several universities form a base for a regional monitoring and alert network.
	The National Institute of Amazonian Research (INPA) contributes infrastructure and scientific expertise, complemented by hydrometeorological programs.
	MapBiomas Fogo and INPE's (National Institute for Space Research) Queimadas system are operational tools for fire management, ready to be linked with local monitoring and health alerts.
	A new Air Quality and Health Surveillance Monitoring Platform for the Amazon, led by Fiocruz with support from the Ministry of Environment and Climate Change (MMA), provides a critical anchor.
	State and municipal initiatives, including those led by SEMA (State Environmental Secretariats), bring local capacity to the system.
Energy transition	Solar + storage mini-grids are already replacing diesel in isolated communities, improving health, reducing emissions, and expanding access.
Transport innovation	NGOs and academic partners have piloted solar-electric boats, demonstrating clean river mobility solutions.
	PAC Mobilidade, a federal program, provides financing opportunities for scaling up river transport electrification.
Waste and urban management	Belém and Manaus are piloting selective collection and composting, creating early entry points for waste sector emissions reduction.
Industry	SUFRAMA's (Manaus Free Trade Zone Authority) green industry initiatives can serve as platforms to introduce industrial emission controls and cleaner production models.
Finance and investment	Large-scale programs such as the World Bank's AM Pro-Sustentabilidade and the IDB/GCF Amazon Bioeconomy Fund together mobilize over US$1.1 billion, providing leverage to embed clean air and health into the Amazon's bioeconomy growth story.



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69 **Why Such Large Variations? Industry** (0.0-106x BCR): The extreme variation reflects fundamentally different intervention types and contexts. The highest performer was the use of electrostatic precipitators (106x BCR), while the lowest performers (approaching 0x) involve costly pollution control retrofits in South Africa with limited health impact relative to expense. **Transport** (0.4-33x BCR): Active mobility infrastructure (33x BCR) delivers exceptional returns in dense urban areas where it reduces both traffic congestion and emissions exposure for large populations. Lower-performing interventions like some clean fuel programs (0.4x BCR) reflect high implementation costs relative to health benefits, often due to limited fleet turnover or weak enforcement mechanisms. **Clean Cooking** (0.7-6x BCR): Clean cookstoves (6x BCR) show strong returns where traditional biomass burning is prevalent and replacement fuels are affordable. Success depends on fuel price ratios, household income levels, cultural cooking practices, and ongoing support for maintenance and fuel supply chains.

TABLE 3. POPULATION FOR TOP 20 MOST POPULATED AMAZONIAN CITIES BETWEEN 2000 AND 2023.

CITY	2000 POPULATION	2023 POPULATION	POPULATION CHANGE	PERCENT CHANGE
Belém/PA	1,921,114	2,535,185	614,071	32%
Manaus	1,405,051	2,311,842	906,791	64.5%
Cuiabá/MT	698,188	925,417	227,230	32.5%
Macapá/AP	363,650	686,655	323,005	88.8%
Porto Velho/RO	349,241	576,320	227,079	65%
Rio Branco	252,984	445,670	192,686	76.2%
Boa Vista	200,401	402,862	202,460	101%
Palmas	137,436	379,480	242,043	176.1%
Parauapebas	71,494	330,832	259,338	362.7%
Marabá	167,983	324,033	156,050	92.9%
Santarém	249,029	314,010	64,981	26.1%
Imperatriz/MA	242,490	278,493	36,002	14.8%
Rondonópolis	150,312	254,764	104,452	69.5%
Araguaína	113,076	200,036	86,959	76.9%
Sinop	74,842	170,912	96,070	128.4%
Tailândia	38,469	162,897	124,428	323.5%
Tucuruí	73,759	127,933	54,174	73.4%
Ji-Paraná	107,142	127,517	20,375	19%
Itaituba	95,392	100,507	5,115	5.4%
Cruzeiro do Sul	68,141	92,887	24,745	36.3%

TABLE 4. ANNUAL AVERAGE PM2.5 CONCENTRATIONS FOR 20 AMAZONIAN CITIES BETWEEN 2000 AND 2023. ANNUAL AVERAGE CONCENTRATIONS DERIVED FROM SATELLITE-DERIVED GRIDDED CONCENTRATIONS FROM HAMMER AND COLLEAGUES (2023).

CITY	2000 (ug/m3)	2023 (ug/m3)	CHANGE (%)	PERCENT CHANGE (%)
Porto Velho/RO	30.1	38.3	8.2	27%
Itaituba /PA	25.2	34.5	9.3	37%
Manaus /AM	21.5	33.3	11.8	55%
Rio Branco /AC	26.8	32.1	5.3	20%
Ji-Paraná /RO	29.9	31.5	1.5	5%
Santarém /PA	16.5	27.3	10.8	65%
Cruzeiro do Sul /AC	18.0	25.6	7.7	43%
Sinop /MT	27.5	24.1	-3.4	-12%
Tucuruí /PA	16.6	22.5	5.9	35%
Parauapebas /PA	19.7	22.2	2.6	13%
Marabá /PA	18.8	22.1	3.3	17%
Cuiabá/MT	21.7	20.1	-1.6	-7%
Tailândia /PA	15.2	19.1	3.9	26%
Imperatriz/MA	14.6	17.8	3.2	22%
Araguaína /TO	16.1	17.3	1.2	8%
Macapá/AP	13.7	17.0	3.3	24%
Belém/PA	13.8	16.7	2.9	21%
Boa Vista /RO	18.8	16.6	-2.2	-12%
Rondonópolis /MT	15.6	15.9	0.3	2%

TABLE 5. COMPARISON OF FINE PARTICULATE MATTER CONCENTRATIONS (PM2.5) (2023), PM2.5-ATTRIBUTABLE DEATHS PER 100,000 (2023), PERCENTAGE OF POPULATION INDIGENOUS (2010) AND MULTI-DIMENSIONAL POVERTY INDEX (MPI).

CITY	PM2.5 (ug/m3)	Death Rate (per 100,000)	Percent (%) Indigenous population	MPI
Santarém	27.29	393	0.83	0.144
Itaituba	34.45	3578	0.78	0.086
Cruzeiro do Sul	25.64	340	1.10	0.089
Tucuruí	22.51	334	0.52	0.101
Boa Vista	16.58	304	3.10	0.155
Manaus	33.27	1,081	0.26	0.091
Parauapebas	22.24	503	0.74	0.034
Ji-Paraná	31.46	501	1.03	0.042
Macapá/AP	17.41	261	0.00	0.115
Cuiabá/MT	20.32	734	0.34	0.019
Belém/PA	17.40	675	0.14	0.048
Rio Branco	32.07	561	0.14	0.053
Porto Velho/RO	38.27	554	0.41	0.079
Sinop	24.08	464	0.23	0.007
Araguaína	17.31	416	0.16	0.042
Tailândia	19.06	414	0.07	0.063
Rondonópolis	15.90	344	0.41	0.037
Marabá	22.11	333	0.22	0.08
Imperatriz/MA	18.20	311	0.22	0.053
Palmas	13.07	283	0.18	0.018

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