Journal of Technology and Innovation 13[31]1-9: e41331109
Article

Decarbonization Part 1: Importance of Particulate Pollution Monitoring in Morelos, Mexico

Descarbonización Parte 1: Importancia del monitoreo de partículas contaminantes en Morelos, México

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Classification:

Area: Physics-Mathematics and Earth Sciences
Field: Earth and space sciences
Discipline: Sciences of the atmosphere
Subdiscipline: Regional climatology

https://doi.org/10.35429/JTI.2026.13.31.4.1.9
History of the article:
Received: January 30, 2026
Accepted: April 30, 2026

Check for updates

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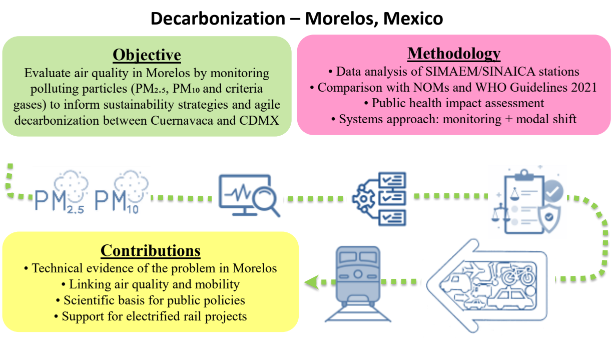
Abstract

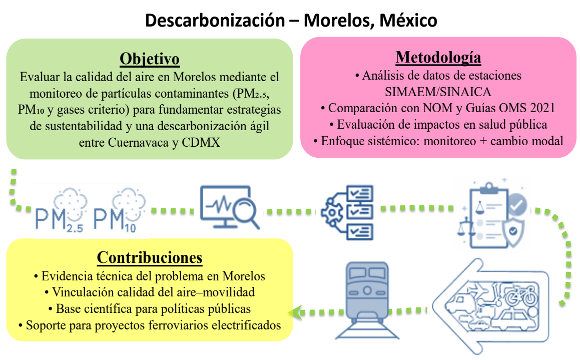
This article highlights the relevance of monitoring particulate pollutants in cities as a key instrument to achieve sustainability goals, protect public health, and mitigate climate change. In this first part, the concepts and fundamentals of the measurement of atmospheric particles are presented, highlighting that fine particulate matter [PM2.5] represents one of the main health risks. Globally, the WHO estimates that air pollution causes around seven million premature deaths a year. In Mexico, more than 32,000 deaths per year are associated with poor air quality, with a significant contribution from mobile sources, responsible for a high proportion of pollutant emissions. In the State of Morelos, particularly in Cuernavaca, concentrations of PM10, PM2.5 and ozone have been recorded that exceed the regulated limits. From this context, the article focuses on Morelos as a case study to underscore the importance of monitoring and explore solutions such as the modal shift towards electrified railway systems between Cuernavaca and Mexico City.



Climate change, decarbonization, particulate matter

Resumen

Este artículo resalta la relevancia del monitoreo de partículas contaminantes en las ciudades como un instrumento clave para alcanzar objetivos de sustentabilidad, proteger la salud pública y mitigar el cambio climático. En esta primera parte se presentan los conceptos y fundamentos de la medición de partículas atmosféricas, destacando que el material particulado fino [PM2.5] representa uno de los principales riesgos sanitarios. A nivel mundial, la OMS estima que la contaminación del aire provoca alrededor de siete millones de muertes prematuras al año. En México, más de 32,000 fallecimientos anuales se asocian a la mala calidad del aire, con una contribución significativa de las fuentes móviles, responsables de una alta proporción de emisiones contaminantes. En el Estado de Morelos, particularmente en Cuernavaca, se han registrado concentraciones de PM10, PM2.5 y ozono que superan los límites normados. A partir de este contexto, el artículo se enfoca en Morelos como caso de estudio para subrayar la importancia del monitoreo y explorar soluciones como el cambio modal hacia sistemas ferroviarios electrificados entre Cuernavaca y la Ciudad de México.



Cambio climático, descarbonización, partículas

Area: Promotion of frontier research and basic science in all fields of knowledge

Citation: Ruiz-Flores, Luis Ivan, Cisneros-Villalobos, Luis, Saldarriaga-Noreña, Hugo Albeiro and Vergara-Sánchez, Josefina. [2026]. Decarbonization Part 1: Importance of Particulate Pollution Monitoring in Morelos, Mexico. Journal of Technology and Innovation. 13[31]1-9: e41331109.

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1. Introduction

A Particulate Pollutant Monitoring Center plays a crucial role in air quality monitoring, especially in regions such as the state of Morelos, Mexico. These centers are responsible for measuring and analyzing various air pollutants, including fine particulate matter [PM2.5], coarse particulate matter [PM10], nitrogen oxides [NOx], carbon dioxide [CO_2], ozone [O_3], carbon monoxide [CO], and sulfur dioxide [SO_2]. Constant monitoring of these pollutants is essential to protect public health and the environment. Particulate matter is measured in PPB and PPM[1] according to *[¿Qué son ppm y ppb?, s. f.*], also, depending on the area or zone to be measured, are used *micrograms per cubic meter*[2] [μg/m³].

In Mexico, there are 34 Air Quality Monitoring Systems [ACMS] distributed in 30 states, which group a total of 249 monitoring stations. These systems allow the population to be informed about pollution levels, activate alerts or emergency procedures, evaluate compliance with Official Mexican Standards [NOM] and monitor air quality management strategies [*Plataforma Estados y Municipios, s. f.*].

Constant and accurate monitoring of polluting particles is crucial to implement effective public policies that protect the health of the population and the environment. In addition, it is essential to comply with international commitments on climate change and move towards agile decarbonization and real sustainability. Investment in monitoring infrastructure and public awareness of air quality must be a priority for governments and society as a whole

Next, the conceptualization of terms and their application in the monitoring of polluting particles will be described. Table 1 shows the main sources that emit these pollutants. On the other hand, according to the WHO, the critical thresholds are mentioned in Table 2.

A. Conceptualization of contaminants

PM2.5: *Fine particulate matter*, particles with a diameter ≤2.5 μm; can penetrate deep into the lungs and enter the bloodstream.

PM10: *Coarse particulate matter,* particles with diameter ≤10 μm; mainly affect the upper respiratory tract.

NOx: *Nitrogen oxides*, gases such as NO and NO_2 produced during combustion at high temperatures.

CO2: *Carbon Dioxide*, a greenhouse gas resulting from the combustion of carbon.

O3: *Tropospheric ozone,* a gas formed by photochemical reactions between NOx and volatile organic compounds under sunlight.

CO: *Carbon Monoxide, a* colorless and odorless gas produced by incomplete combustion of carbon.

SO2, *Sulphur Dioxide,* Irritating gas produced by the combustion of sulphur in fossil fuels.

B. Background of monitoring of polluting particles.

The United Kingdom began in 1914 with an instrument that collected soil particles such as soot or dust using a device called a deposit meter or known at the time as a deposit meter *"deposit gauge"* [*Shaw & Owens, 1925*]. This device developed by the Committee for the Research of Air Pollution led by *John Switzer Owens*. By 1996, the United Kingdom reported 1,000 monitoring stations establishing the first large-scale air pollution monitoring network. Each of the devices made it possible to quantify the amount of soot and other particles deposited in the air, marking the beginning of structured air pollution monitoring [*2003 - Air Pollution in the UK 2002.pdf, n.d.*].

Air pollution is one of the major environmental threats to human health and global ecological systems. Particulate matter and reactive compounds such as $PM_{2.5}$, PM_{10}, NOx, and O_3 have been associated with multiple harms to respiratory and cardiovascular health, as well as adverse ecological effects. Since 2021, the WHO has updated its Global Air Quality Guidelines based on robust scientific evidence, noting that continued exposure to $PM_{2.5}$ levels above 5 μg/m³ and other pollutants is associated with significant risks to human health, even below many current national standards [*Las nuevas Directrices mundiales de la OMS sobre la calidad del aire tienen como objetivo evitar millones de muertes debidas a la contaminación del aire, s. f.*].

[1] *PPB (Parts Per Billion) and PPM (Parts Per Million*) are units used in atmospheric chemistry to describe the concentration of gases.

[2] μg/m³: It is a unit of measurement that is used to express the concentration of a pollutant in the air, for example, ozone or particles. 1 μg/m³ of air contains a certain amount of micrograms of that pollutant.

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In the Mexican context, the *National Air Quality Information System* [SINAICA] operates networks of stations that monitor the main air pollutants in states such as Morelos, including the urban area of Cuernavaca [*Instituto Nacional de Ecología y Cambio Climático - Calidad del aire*, s. f.].

C. Methodology and Anthology of Contaminant Monitoring in Morelos, Mexico

In this article we highlight the importance of monitoring polluting particles in cities. This is to contribute to achieving sustainability objectives and combating global warming. In this first part of the article, we will define the concepts and fundamentals of measuring polluting particles, as well as highlight the objective of monitoring pollutant particles in the air. This is because it is an essential mechanism for safeguarding public health and mitigating the effects of climate change. Globally, the World Health Organization [WHO] estimates that air pollution causes around seven million premature deaths each year, with fine particulate matter [PM2.5] being one of the main culprits. These particles, when inhaled, can penetrate deep into the lungs and circulatory system, causing respiratory and cardiovascular diseases and cancer. In Mexico, the situation is equally worrying. According to the Mexican Center for Environmental Law [CEMDA], more than 32,000 people die annually in the country due to poor air quality, mainly due to exposure to particulate matter. Mobile sources, such as motor vehicles, generate 63% of carbon monoxide [CO] emissions, 44% of nitrogen oxides [NOx] and 14% of PM2.5. In addition, 52.4% of cities and metropolitan areas with PM10 capacity exceeded the normative limit, and 47.2% of regions with PM2.5 capacity also exceeded the established limits [*«Calidad del aire», s. f.*].

In the State of Morelos in Mexico, specifically in the city of Cuernavaca, worrying levels of atmospheric pollutants have been recorded. An air quality diagnosis in 2016 revealed that the normative limits for at least one pollutant were exceeded. The 24-hour average concentration of PM10 reached 98 µg/m³, 1.7 times higher than the allowable value of 75 µg/m³. For PM2.5, concentrations of 69 µg/m³ were recorded on a 24-hour average, 1.4 times the normative value of 45 µg/m³, and an annual average of 19 µg/m³, 1.6 times the annual allowable limit of 12 µg/m³.

In addition, the ozone standard was breached by reaching an 8-hour average concentration of 0.080 ppm, slightly above the limit of 0.070 ppm [*Gomez - 2016 - Informe nacional de calidad del aire 2015.pdf, s. f.*]. In this article, we will focus on the State of Morelos, Mexico where there are facts and figures that will allow us to start this series of articles to highlight the importance of monitoring polluting particles and how it can contribute to projects that contribute to agile decarbonization using rail and train transport between cities such as Cuernavaca and CDMX.

Box 1

Table 1

Urban air pollutants

Pollutant	Main Sources	Health Effects	Impact Figures	Mitigation Measures
PM2.5 [Fine Particulate Matter]	Vehicle combustion, industries, biomass burning, urban dust.	Asthma, COPD, cardiovascular diseases, lung cancer, cognitive impairment.	4.2 million premature deaths in 2015 worldwide [*Lelieveld et al., 2015*]	Regulation of vehicular and industrial emissions, promotion of public transport, use of HEPA filters.
PM10 [Coarse Particulate Matter]	Construction, vehicular traffic, agricultural activities, soil dust.	Eye and nasal irritation, exacerbation of respiratory diseases.	Exceeding 50 µg/m³ increases respiratory hospitalizations. [*content.pdf, s. f.*]	Dust control in construction sites, paving of roads, wet sweeping of streets.
Nox [Nitrogen Oxides]	Motor vehicles, power plants, industrial processes.	Lung irritation, tropospheric ozone formation, contribution to acid rain.	Connection with increases in hospitalizations due to asthma. [*Hoek et al., 2013*]	Selective catalytic reduction, use of cleaner fuels.
CO_2 [Carbon Dioxide]	Burning of fossil fuels, deforestation, industrial processes.	It contributes to climate change, indirectly affecting human health.	Over 420 ppm in 2023 [*Broken Record, 2023*]	Renewable energies, energy efficiency, reforestation.
O_3 [Tropospheric Ozone]	Vehicle emissions, industrial solvents, power plants.	Respiratory irritation, reduced lung function, exacerbation of asthma.	22,000 premature deaths annually in the EU [*Air Pollution Levels Still Too High across Europe – Remains Top Environmental Health Risk, 2023*]	Reduction of precursor emissions, clean transport.
CO [Carbon Monoxide]	Vehicles, domestic heating, fires.	It interferes with the transport of oxygen in the blood, neurological and cardiovascular effects.	Chronic exposure damages organs [*Health and Environmental Effects of Particulate Matter [PM] | US EPA, s. f.*]	Vehicle maintenance, ventilation, CO detectors.
SO_2 [Azufre Dioxide]	Power plants, industries, volcanoes.	Eye and respiratory irritation, acid rain.	High exposure associated with respiratory mortality. [*Air quality guidelines global update 2006., s. f.*], [*Orellano et al., 2021*] [*Karimi & Shokrinezhad, 2021*]	Low-sulphur fuels, desulfurisation, monito

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Box 2

Table 2

Advantages and Disadvantages of High Levels of Pollutants according to WHO and tropicalization of NOMs [*Las nuevas Directrices mundiales de la OMS sobre la calidad del aire tienen como objetivo evitar millones de muertes debidas a la contaminación del aire, s. f.*] y [*Dirección de Monitoreo Atmosférico, s. f.*]

Pollutant	Critical Threshold [Normative/WHO]	Advantages of Elevated Monitoring	Disadvantages of High Levels
$PM_{2.5}$	> 5 µg/m³ [annual WHO]	Identifies risk exposures and enables health alerts.	Associated with respiratory and cardiovascular mortality and morbidity.
PM_{10}	> 15 µg/m³ [annual WHO]	It focuses on local emission reduction policies.	Respiratory irritation and systemic effect.
Nox	There is no specific WHO annual threshold*	It allows you to control transport emissions.	Contributes to O_3 formation and acid rain.
O_3	> 0.058 ppm [NOM]	It indicates industrial/urban photochemical reactions.	It increases pulmonary oxidative stress and damages vegetation.
CO	> 10 mg/m³ [OMS 8 h]	Detects incomplete combustion sources.	It interferes with the transport of O_2 in the blood.
SO_2	> 500 µg/m³ [max 10 min, OMS]	Monitor industrial emissions.	It causes acute irritation and contributes to secondary PM.

Note: The specific threshold values are a combined reference of WHO and Mexican NOMs; the WHO recommends intermediate targets in addition to guidelines.

In the current context of environmental management, air quality monitoring in states such as Morelos is a fundamental tool for the protection of public health, the formulation of environmental policies and the construction of strategies for mitigation and adaptation to climate change. The systematic measurement of air pollutants – such as $PM_{2.5}$, PM_{10}, NOx, O_3, CO and others – makes it possible to identify emitting sources, assess compliance with national and international standards, and guide effective corrective actions.

Monitoring stations operate in the State of Morelos, including the *"Cuernavaca 01 [PGO]" station,* which is part of the local atmospheric monitoring network and SINAICA. This station measures multiple pollutant parameters: CO, NO, NO_2, NOx, O_3, PM_{10}, $PM_{2.5}$ and SO_2, along with meteorological variables.

Continuous monitoring allows us to obtain hourly and daily data that are translated into indicators such as the *Air Quality Index [AQI]* or, at the level of the Metropolitan Area of the Valley of Mexico, the IMECA [Metropolitan Air Quality Index].

2. Importance of monitoring polluting particles in Morelos, Mexico.

Air quality monitoring is a critical environmental management tool for assessing, controlling, and mitigating the impacts of air pollutants on human health and ecosystems. In the state of Morelos, Mexico, the atmospheric monitoring network [SIMAEM/SINAICA] continuously measures criterion pollutants such as $PM_{2.5}$, PM_{10}, NO_x, O_3, CO and SO_2, whose presence in high concentrations is associated with multiple adverse effects on health and social welfare.

Particulate matter [PM], particularly fine $PM_{2.5}$ fractions, penetrate deep into the respiratory system, increasing the prevalence of cardiorespiratory diseases and premature mortality [*Saldarriaga-Noreña et al., 2015*].

The **Official Mexican Standard NOM-025-SSA1-2021** establishes progressive limit values for $PM_{2.5}$ and PM_{10} in order to protect population health, aligning with international guidelines although still above the levels recommended by the WHO [*NOM-025-SSA1-2021 – Normalización, s. f.*].

In Morelos, data from monitoring stations such as *Cuernavaca 01 [PGO]* show that during certain periods of the year the concentrations of $PM_{2.5}$ and PM_{10} reach values that can exceed healthy categories, with implications for sensitive groups [*Instituto Nacional de Ecología y Cambio Climático - Calidad del aire*, s. f.].

Continuous monitoring not only allows compliance with regulatory criteria, but also enables the issuance of health alerts, the evaluation of temporal trends and the planning of structured public policies. This white paper presents an analysis of critical contaminants, compares thresholds with international guidelines, and discusses advantages and disadvantages of elevated levels.

The importance of focusing emission reduction strategies, optimizing measurement networks, and adopting management approaches based on scientific evidence to improve air quality in Morelos and metropolitan areas such as the ZMVM is emphasized.

The State of Morelos, although it is not one of the entities with the worst national averages, requires specific attention in terms of air quality.

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Real-time monitoring, available on public platforms, shows that cities such as **Cuernavaca** have PM2.5 concentrations of around 23 µg/m³ and PM10 of 58 µg/m³ in recent periods, levels that exceed several times the WHO-recommended annual guideline value for PM2.5 [5 µg/m³] [*Índice de la calidad del aire [ICA] de Cuernavaca y contaminación del aire en México | IQAir*, s. f.]. These figures underscore that, even in states with less industrialization, emissions from mobile sources, fuel burning and weather conditions can result in concentrations of particulate matter that compromise health.

A. International air quality standards to link to figures in Morelos

The WHO Global Air Quality Guidelines published in 2021 provide guidance for the main pollutant criteria, based on a systematic review of the literature and a formal process for assessing the certainty of the evidence. These values are stricter than the previous ones and are aimed at minimizing the burden of disease attributable to air pollution. Table 3 summarises, in a simplified way, the proposed guide values for the most relevant pollutants.

The values in Table 3 are based on a series of systematic reviews published in a special edition of the journal *Environment International* [*Pérez Velasco & Jarosińska, 2022*], which synthesizes associations between long-term exposure to particulate matter and gases and all-cause mortality, as well as respiratory and cardiovascular effects.

Box 3

Table 3

Guiding values according to the WHO linking to short-term values according to [*Pérez Velasco & Jarosińska, 2022*]

Pollutant	Annual Guide Value	Short-term guide value
PM2.5	5 µg/m³ per year	15 µg/m³ 24 h
PM10	15 µg/m³ per year	45 µg/m³ 24 h
O_3	–	60 µg/m³ [≈0.03 ppm] máx. 8 h
NO_2	10 µg/m³ per year	25 µg/m³ 24 h
SO_2	–	40 µg/m³ 24 h
CO	–	4 mg/m³ [≈3.5 ppm] of mice. 24 h

B. Example of values reported in 2021 by Pollutants in Morelos.

Table 4 shows the values reported by environmental parameters and pollutants according to "*Cuernavaca 01 [PGO"* for the year 2021. In 2023, the author received a record of previous years from SEDESU and registered in the instruments of the monitoring center. In order to graph the data of the parameters, statistical techniques are used and placed in a standard way that are shown in Figure 1.

Box 4

Table 4

Reported values of environmental parameters in 2021

Reported values							
	CO	**O3**	**Relative humidity**	**°C**	**Wind Speed**	**PM10**	**SO2**
	2021	**2021**	**2021**	**2021**	**2021**	**2021**	**2021**
January	0.400	0.032	41.000	20.900	2.571	38.000	0.002
February	0.470	0.038	30.000	21.890	2.659	51.000	0.002
March	0.520	0.040	30.000	24.370	2.422	76.000	0.001
April	0.520	0.043	27.000	25.690	2.432	68.000	0.001
May	0.520	0.036	46.000	24.390	2.073	39.000	0.001
June	0.520	0.020	68.000	21.600	1.827	19.000	0.001
July	0.460	0.027	55.000	22.970	1.967	29.000	0.001
August	0.420	0.023	63.000	22.260	2.388	21.000	0.009
September	0.450	0.018	73.000	21.080	4.232	20.000	0.001
October	0.435	0.023	73.000	21.180	3.444	30.500	0.002
November	0.435	0.023	73.000	21.180	3.444	30.500	0.002
December	0.435	0.027	73.000	21.280	2.655	41.000	0.002

Box 5

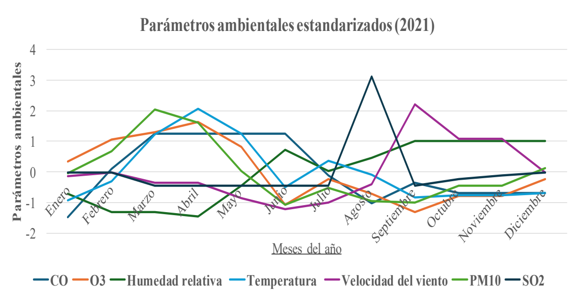

Figure 1

Normalized environmental parameters and pollutants in 2021

Source: Own elaboration

Table 3 and Figure 1 show that PM10 concentrations in Morelos range, depending on the month, between values close to 19 µg/m³ and values above approximately 50 µg/m³. The annual mean is around 30–35 µg/m³, with a notable standard deviation that shows high seasonal variability.

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These values, even in the months with the lowest records, exceed the annual guideline value of 15 μg/m³ established by the WHO, and in the months with maximums they approach or exceed the daily guideline value of 45 μg/m³.

For ozone [O_3], monthly averages typically fall between 0.018 and 0.043 ppm, with highs in spring and early summer. Although the available data are presented as monthly averages and not as 8-hour moving averages, WHO guidelines indicate that chronic exposures above 60 μg/m³ [approximately 0.03 ppm] in 8-hour periods are associated with significant increases in respiratory morbidity. The presence of several months with averages around or above 0.03 ppm suggests that episodes of maximum exposure may easily exceed the guideline values.

Carbon monoxide [CO] has monthly values between approximately 0.40 and 0.52 ppm, with an annual average of about 0.46 ppm and moderate or low variations between months. These levels are well below the WHO guideline value for 24-hour exposures [in the order of 4 mg/m³, equivalent to approximately 3.5 ppm], so that, in terms of international standards, CO is not the most critical pollutant in the context of Morelos. However, it acts as a tracer of the intensity of vehicular combustion and is interpreted as an indirect indicator of the weight of transport on air quality.

Sulphur dioxide [SO_2] shows relatively low values in Table 3 of 2021, with no indications of systematic exceedance of the short-term guide values. However, its presence is considered important as it contributes, together with nitrogen oxides [NOx] and particulates, to secondary aerosol formation processes and local acidification.

The absence of explicit NO_2 and PM2.5 data in the file received by the author limits the possibility of a comprehensive assessment, but considering the correlation reported in multicenter studies, it is reasonable to assume that areas with high PM10 and heavy traffic also have relevant NO_2 concentrations.

C. Data reported in real-time from [Instituto Nacional de Ecología y Cambio Climático - Calidad del aire, s. f.] y [Índice de la calidad del aire [ICA] de Cuernavaca y contaminación del aire en México | IQAir, s. f.] ***para contaminantes PM2.5 y PM10 en Cuernavaca***

To complement the information on pollutants, the data reported by *IQAir* and *SINAICA* in the pollutants $PM_{2.5}$ has registered values around **10–14 μg/m³** in certain recent periods, while PM_{10} has been observed in ranges close to **28–43 μg/m³**. These values may exceed the thresholds recommended by the WHO, especially for $PM_{2.5}$ [e.g. 5 μg/m³ annual average recommended by the WHO in 2021]. The *WHO Global Guidelines on Air Quality* [2021] recommend stricter target levels than many national standards, based on scientific evidence of mortality and morbidity attributable to air pollution. The recommendations include goals to:

- Average annual $PM_{2.5} \leq 5$ μg/m³.
- Average annual $PM_{10} \leq 15$ μg/m³.

These guidelines, although not legally binding, serve as a scientific basis for strengthening national norms and public policies.

D. Comparison with the ZMVM and International Context

Mexico City and its metropolitan area [including Cuernavaca] have historically had episodes of elevated levels of $PM_{2.5}$, PM_{10} and O_3, frequently above Mexican regulatory limits and WHO guidelines, especially during dry seasons and thermal inversions. On the other hand, according to recent global reports, most cities in the world exceed the WHO guidelines for $PM_{2.5}$, and only a few countries managed to meet these targets by 2024 [*Niranjan & correspondent, 2025*].

In regions such as **India** y **Bangladesh**, $PM_{2.5}$ averages far exceed WHO recommendations. **China** has achieved significant reductions in $PM_{2.5}$ and is strengthening standards and monitoring systems to eliminate severe pollution *[Stanway & Stanway, 2024*].

3. Justification for pollutant monitoring in Morelos.

Air pollution is one of the main global environmental threats, associated with adverse effects on human health – including respiratory diseases, cardiovascular diseases and premature mortality – and with negative impacts on ecosystems. Particulate matter and reactive gases are criteria pollutants and are monitored through networks of air quality monitoring stations [*NOM-025-SSA1-2021 – Normalización*, s. f.].

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https://doi.org/10.35429/JTI.2026.13.31.4.1.9

The state of Morelos, along with the Metropolitan Area of the Valley of Mexico [ZMVM], faces recurrent episodes of elevated levels of fine particles and other pollutants due to mobile [vehicles], fixed [industrial activities], and area [biomass burning] sources. Continuous monitoring of these parameters is essential to evaluate compliance with sanitary standards and develop environmental and public health management strategies.

A. Benefit of monitoring contaminants

In Morelos, the *Atmospheric Monitoring System of the State of Morelos* [SIMAEM], integrated into the *National Air Quality Information System* [SINAICA]. The Station *Cuernavaca 01 [PGO]* it is one of the main ones, measuring pollutants such as CO, NO, NO_2, NO_x, O_3, PM_{10}, $PM_{2.5}$ and SO_2 in real time, allowing air quality to be evaluated and conditions to be communicated to the population [*Índice de la calidad del aire [ICA] de Cuernavaca y contaminación del aire en México | IQAir*, s. f.]

B. Comparison of monitored levels in Morelos in 2021

In Morelos, air quality data show that $PM_{2.5}$ and PM_{10} concentrations show seasonal variability. At certain times of the year, levels can rise to ranges considered negative for health, particularly for vulnerable groups such as children, older adults, and people with chronic diseases [*Instituto Nacional de Ecología y Cambio Climático - Calidad del aire*, s. f.].

This is consistent with the literature that identifies moderate to high concentrations of fine particulate matter with public health implications [*Brito-Hernández et al., 2024*].

In parallel, the new WHO Global Air Quality Guidelines have significantly tightened the reference values for classic pollutants such as PM2.5, PM10, NO_2, SO_2, O_3 and CO, reflecting a robust scientific consensus around the risks associated with exposures even below the previous limits. This hardening implies that many urban and peri-urban areas, including regions such as Morelos, have systematically exceeded the recommended values, which forces us to rethink structural policies in transport and land use.

The detailed analysis of Morelos' air quality data for 2021 shows that PM10 and ozone concentrations are recurrently outside the ranges established by the 2021 WHO Global Guidelines, implying an avoidable burden of disease and mortality attributable to air pollution. Carbon monoxide, although below its guide values, confirms the persistent presence of emissions associated with motorized transport.

4. Conclusions

The permanent monitoring of polluting particles and gases makes it possible to understand spatio-temporal patterns, evaluate the exposure of the population to adverse conditions and structure public health policies. At the international level, several countries have established monitoring systems and mitigation strategies to improve air quality; however, incomplete infrastructure and gaps in coverage can limit the reach of programs in regions such as Morelos.

Monitoring systems, which combine fixed stations and sensor networks, are essential to inform the population and authorities about pollution levels, activate early warnings and design environmental mitigation strategies. Without continuous monitoring, populations are left vulnerable to prolonged exposures without detection or timely response. In Morelos, the availability of real-time data allows for variations in air quality to be observed and local interventions to be guided, reinforcing the need for **robust measurement infrastructure and data transparency** to evaluate environmental public policies.

Air quality monitoring in Morelos is essential for public health protection, regulatory planning, and environmental management. The information generated by stations such as *Cuernavaca 01 [PGO]* makes it possible to evaluate compliance with standards, detect pollution events and guide strategic decisions for the reduction of emissions and risk mitigation.

The continuous monitoring of air pollutants in Morelos plays an essential role in the protection of public health and the design of effective environmental policies. The monitoring of $PM_{2.5}$, PM_{10}, NOx, O_3 and other parameters, compared to WHO standards and Mexican regulations, provides critical information to implement mitigation strategies, health alerts and decarbonization plans.

ISSN: 2410-3993.
RENIECYT: 1702902
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Ruiz-Flores, Luis Ivan, Cisneros-Villalobos, Luis, Saldarriaga-Noreña, Hugo Albeiro and Vergara-Sánchez, Josefina. [2026]. Decarbonization Part 1: Importance of Particulate Pollution Monitoring in Morelos, Mexico. Journal of Technology and Innovation. 13[31]1-9: e41331109. https://doi.org/10.35429/JTI.2026.13.31.4.1.9

Comparison with systems such as IMECA in the ZMVM and international experiences underscores the need to strengthen monitoring, communication and normative action.

In this context, **the implementation of an Electrified Suburban Train between Cuernavaca and Mexico City** appears as a structurally coherent measure with the goals of air quality, decarbonization and sustainable mobility. Comparison with recent rail projects in Mexico suggests that the order of magnitude of the costs is significant but manageable, especially considering the benefits in emissions reduction, safety, travel times, and regional economic development.

It is recommended to move towards pre-feasibility studies that integrate demand analysis, basic layout engineering and electrification, strategic environmental assessment and public-private financing schemes, in alignment with international air quality and railway electrification standards. A rigorously substantiated design would maximize the climate, health and economic co-benefits for the Cuernavaca-CDMX region.

Declarations

Conflict of interest

The authors declare that there is no conflict of interest. They have no competing financial interests or known personal relationships that could have influenced the article recounted in this article.

Author's contribution

Ruiz-Flores, Luis Iván: Development of field research with government entities, capture of data in graphs, writing [revision and editing].

Cisneros-Villalobos, Luis: Conceptualization, methodology and supervision.

Saldarriaga-Noreña, Hugo Albeiro: Formal analysis of 2021 data and research.

Vergara-Sánchez Josefina: Formal analysis and research.

Availability of data and materials

The original contributions presented in this study are included in the article. For more information, please contact the corresponding author.

Funding

This research did not receive any funding.

Acknowledgements

Thank you for the opportunity of the Autonomous University of the State of Morelos [UAEM] with the DIAyTS Doctoral Program to which I am enrolled and currently studying in 2026.

Abbreviations

CDMX	Mexico City
CEMDA	Mexican Center for Environmental Law
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
HEPA	High Efficiency Particle Arresting
NOM	Official Mexican Standards
NOx	Nitrogen Oxides
O_3	Ozone
WHO	World Health Organization
PM10	Coarse Particles
PM2.5	Fine Particles
PPB	Parts per billion [Partes por billon]
PPM	Part per million
SMCA	Air Quality Monitoring Systems
SO_2	Azufre Dioxide

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ISSN: 2410-3993.
RENIECYT: 1702902
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