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The cover image shows a copy of the 1987 UN report “Our Common Future – The report of the world Commission on Environment and Developments”. The picture has been taken in TeMA Lab in July 2023. On the bottom, there is a collage made up of four pictures of recent climate disasters (Source: Google images)

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Nanoparticles on electric, gas and diesel buses in mass transit buses of Bogotá Colombia

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Abstract

The concentration of traffic-related air pollutants (TRAP) within transport microenvironments has become increasingly relevant in many megacities with high population density, intense traffic, and prolonged travel times. These conditions can intensify exposure to TRAP and exacerbate public health problems. However, TRAP concentrations in these microenvironments are changing due to the introduction of cleaner technologies. In this study, we compared the concentration of nanoparticles inside diesel, gas, and electric buses during their normal operation in Bogota, Colombia. We used a miniature diffusion size classifier (DiSCmini) to measure the nanoparticles' concentrations, average particle size, and lung-deposited surface area. Our results revealed significantly lower levels of this pollutant inside electric buses. Specifically, the concentration of nanoparticles per cubic centimeter was approximately 41% and 27% lower in electric buses compared to diesel and gas buses, respectively. Additionally, the lung-deposited surface area was also lower in electric buses. However, the average particle size in electric buses was 10% and 18% smaller compared to diesel and gas buses, respectively. The results of this study give useful information for future selection processes of bus technologies for public passenger transport in cities around the world; This research provides information that can be used in technical evaluation processes that link the possible health effects on commuters and impacts the environment.

Keywords

Diesel buses; BEV electric buses; CNG compressed natural gas buses; Nanoparticles; LDSA lung deposited surface area; Mass transit system.

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1. Introduction

Urban sprawl is recognized as a significant issue, particularly due to its negative impact on environmental sustainability, economic efficiency, and social implications (Hernandez, 2012). From a technical perspective, it leads to the consumption of rural land, reliance on automobiles, and increased carbon emissions. Additionally, it results in the abandonment of inner-city locations, underutilization of urban infrastructure, and the need for new infrastructure in peripheral areas. Mobility, as defined by the Larousse dictionary, refers to the property or characteristic of being capable of movement and changing place or function. It can also be seen as a concept that encompasses the practices of people moving to engage in specific activities (Ghédira & El Kébir, 2022).

In urban environments, air pollution has become a growing concern, particularly due to evidence of significant health impacts caused by previously accepted levels of air pollutant concentrations (Zargari & Khan, 2010). Among the various microenvironments in cities, mass transit areas may expose a larger number of city dwellers to higher concentrations of traffic-related air pollutants (TRAP) (de Nazelle et al., 2017; de Nazelle et al., 2012; Gurram et al., 2019; Hoffmann, 2019; Matz et al., 2019; Morales et al., 2017; Shekarrizfard et al., 2020; Spinazzé et al., 2015). Most mass transportation systems rely on buses, which can be classified as heavy-duty vehicles. Over the past decade, Euro VI and Euro V diesel buses equipped with diesel particulate filters (DPF), Compressed Natural Gas (CNG) powered buses, and battery electric vehicles (BEV) buses have become increasingly common in mass transit systems of many cities (Kholod & Evans, 2016; Morales et al., 2018; Wang et al., 2015).

Heavy-duty vehicles significantly contribute to particulate matter emissions in many cities (Ali et al., 2019; Giechaskiel, 2018; Gireesh et al., 2021; Rodrigues et al., 2020; Winkler et al., 2018), with diesel engines being the primary emitters of ultrafine particles in urban areas (Bessagnet et al., 2022; Hudda et al., 2020; Kwon et al., 2020; Myung & Park, 2011). Natural gas vehicles may emit less soot and particulate matter by mass but potentially more particles by number (Bielaczyc et al., 2015; Chen et al., 2018; Distaso et al., 2020), which could have more significant health effects due to a larger surface area to mass ratio (Deng et al., 2019; Ohlwein et al., 2019; Schraufnagel, 2020). Although fewer studies have examined nanoparticles emitted by BEV vehicles, non-exhaust particulate matter from BEV vehicles could occasionally surpass particulate emissions from internal combustion engines (Beddows & Harrison, 2021; Liu et al., 2021; Zimakowska & Laskowski, 2022). The progressive electrification of vehicles in circulation presents a potential solution to address air pollution-related issues (Maternini et al., 2014).

In Bogotá, a city with a population of over seven million residents, the mass transit system comprised approximately 9,400 buses by 2021, utilizing various technologies. Table 1 illustrates the evolution of bus technologies, highlighting a decrease in the number of buses with standards lower than EURO V and an increase in the number of buses employing less polluting technologies (see Table 1). Furthermore, in 2021, 470 new battery electric vehicles (BEV) buses were introduced into operation, and it is anticipated that the city will have approximately 1,500 BEV buses by the end of 2022.

Significant improvements were observed in the concentrations of fine particulate matter and black carbon within Bogotá's bus rapid transit (BRT) system, a segment of the city's mass transit system. These improvements, amounting to approximately 80%, were a result of the fleet upgrade that involved the deployment of diesel EURO V buses equipped with particulate filters and EURO VI compressed natural gas (CNG) buses (Morales et al., 2022). Primarily, the older EURO II/III buses were replaced during this fleet upgrade, potentially leading to a positive effect on reducing nanoparticle exposure levels. However, the measurements conducted did not include the BEV buses that commenced operations after January 2021.

This research presents data obtained from measurements and analyzes the concentration, average size, and lung-deposited surface area of nanoparticles exposed within diesel, CNG, and BEV buses operating within the zonal component of Bogotá's mass transit system, during their regular operations. Furthermore, a comparison is made to assess variations and determine whether differences in bus technology impact commuters' exposure to nanoparticles.

Technology	2013	2015	2017	2020	2022
< Euro IV	1,338	3,148	2,703	1,824	749
Euro IV	138	983	964	972	986
Euro V	125	2,369	2,666	2,656	3,327
HYbrid		56	56	56	56
Euro VI – CNG			3	2,498	1,490
BEV			1	484	1,128

Tab.1 Bogota's mass transit fleet technology share

2. Methods and data

2.1 Study domain

The mass transit system in Bogotá comprises two components: a Bus Rapid Transit (BRT) system and a zonal component. The BRT system operates articulated and bi-articulated buses on exclusive lanes, while single-body buses are used to feed end-of-line stations on mixed traffic lanes (refer to Fig.1). The zonal component employs single-body buses and operates a mixture of diesel, compressed natural gas (CNG), hybrid (diesel-BEV), and battery electric vehicle (BEV) buses mainly on mixed traffic lanes (refer to Fig.2). In this study, our focus was on measuring exposure inside diesel, CNG, and BEV buses of the zonal component operating on the Carrera 13 route, which runs from West to East and covers the localities of Fontibón, Kennedy, Puente Aranda, Los Mártires, Antonio Nariño, and Santa Fe (refer to Fig.3). The selected buses, lines, and their respective technologies, as well as some route characteristics, are presented in Tab.2.

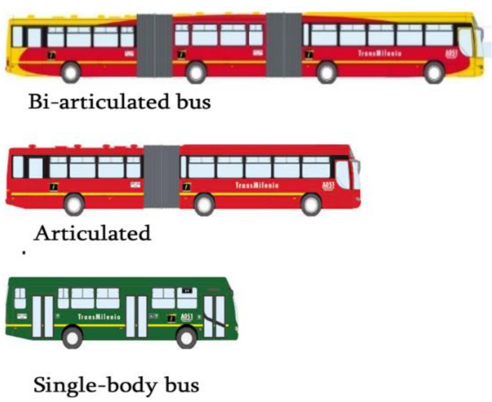

Fig.1 Buses used by the BRT component

To collect the measurements, a person carried the instruments with the inlet nozzle positioned at the breathing zone and free from obstructions. The person consistently traveled at the back between the second and third doors of the buses (refer to Fig.2). This particular area receives the highest number of users and is closer to the engines. The data were recorded every 10 seconds. The measurement days were carefully chosen to represent average operating conditions and were limited to business days. We conducted measurements outside the hours of vehicular restrictions and during typical weather conditions for the city, avoiding periods

of heavy rainfall. Any days with atypical events such as protests or car-free days were excluded from the analysis.
Inside single-body buses, measurements were taken for 80 passengers across all three technologies. It was verified that the tested diesel and CNG buses had no post-treatment or filter installed to control emissions. Tab.3 provides information on the tested bus characteristics (technology, standard, brand, last oil change on km) as well as details about the measurements (date, location, and route).

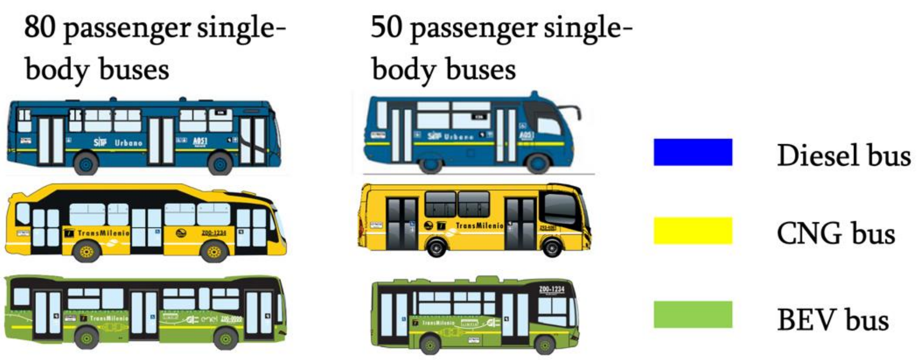

Fig.2 Buses used on the zonal component

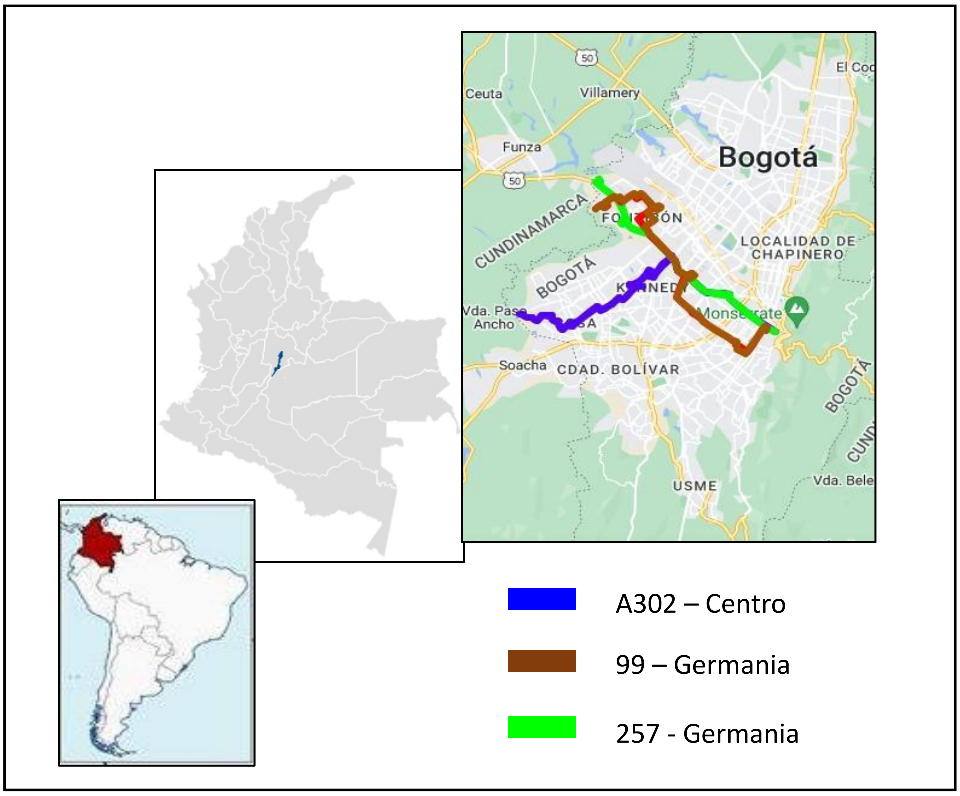

Fig.3 Selected routes in Bogotá in Colombia

Route Name	Bus Technology	Bus stops	Origin	Destination
A302 – Centro	BEV	62	Kr 123 - Cl 14 / Fontibon	AC 19 – Kr 9 / Las Nieves
99 – Germania	Gas	64	Tv 80i – Dg 89 b South / Bosa	AC 19 – Kr 4 / Las Nieves
257 - Germania	Diesel	37	Cl 17d – K135 / Fontibon	AC 19 - Kr 5 / Veracruz

Tab.2 Bus routes measured

Bus Technology	Standard	Brand	last oil change (km)	Date of monitoring	Location *	Total rides *
BEV	BEV	BYD	8.174	05/05/2021	E-W	1
BEV	BEV	BYD	7.140	13/05/2021	E-W / W-E	2
BEV	BEV	BYD	9.327	20/05/2021	E -W	1
CNG	Euro VI	Volkswagen	11.320	07/05/2021	W-E	1
CNG	Euro VI	Volkswagen	6.908	13/05/2021	E -W / W-E	2
CNG	Euro VI	Volkswagen	12.730	21/05/2021	E -W	1
Diesel	Euro VI	Volvo	4.600	20/05/2021	E -W / W-E	2
Diesel	Euro VI	Volvo	5.230	25/05/2021	E -W / W-E	2

Tab.3 Buses measured / * E: East / W: West

2.2 Instruments

We used the miniature diffusion size classifier - DiSCmini (Testo SE & Co. KGaA, Titisee-Neustadt, Germany) portable device to measure the number concentrations (# cm-3) of particles between 10 to 700 nm in size. The instrument also reports the mean nanoparticle diameter (nm), and the lung-deposited surface area (µm2.cm-3), with a frequency of 0.1 Hz.

3. Results

The measurements for BEV buses were conducted on four different dates, with three measurements in the West-to-East (W-O) direction and one measurement in the East-to-West (O-W) direction. In total, the measurements covered a duration of 177 minutes and a distance of 37.24 km. The average nanoparticle concentration was found to be 108,519.5 particles per cubic centimeter (#.cm-3), with a mean nanoparticle diameter of 35.2 nm and an average lung-deposited surface area of 191.6 µm2.cm-3.

Bus technology	BEV	CNG	DIESEL
Total records	841	929	851
Total buses	3	3	2
Total routes	4	4	4
Average nanoparticle concentration (#.cm^{-3})	109,773.0	124,075.6	175,000.5
Max Nanoparticle Concentration(#.cm^{-3})	492,263	495,730	1,247,418
Min Nanoparticle Concentration(#.cm^{-3})	13,556	18,590	14,526
Average Nanoparticle Diameter (nm)	35.2	42.7	37.6
Average Average Lung-Deposited Surface Area (μm^2. cm^{-3})	195.0	281.5	349.6

Tab.4 Summary of measurements and data

For the Diesel buses, four measurements were conducted, with two measurements in the W-O direction and two measurements in the O-W direction. The total duration of these measurements was 225 minutes, covering a distance of 47.62 km. The average nanoparticle concentration for Diesel buses was 166,558.6 #.cm-3, with a mean nanoparticle diameter of 37.2 nm and an average lung-deposited surface area of 344.31 µm2.cm-3.

Similarly, the CNG buses were measured four times, with two measurements in the W-O direction and two measurements in the O-W direction. The total duration of these measurements was 233.4 minutes, covering a distance of 51.45 km. The average nanoparticle concentration for CNG buses was 142,920.8 #.cm-3, with a mean nanoparticle diameter of 42.39 nm and an average lung-deposited surface area of 318.5 µm2.cm^{-3}. Tab.4 presents a summary of the measurements and data obtained for each bus technology, while Fig.4 illustrates the nanoparticle concentrations for each bus technology on each route.

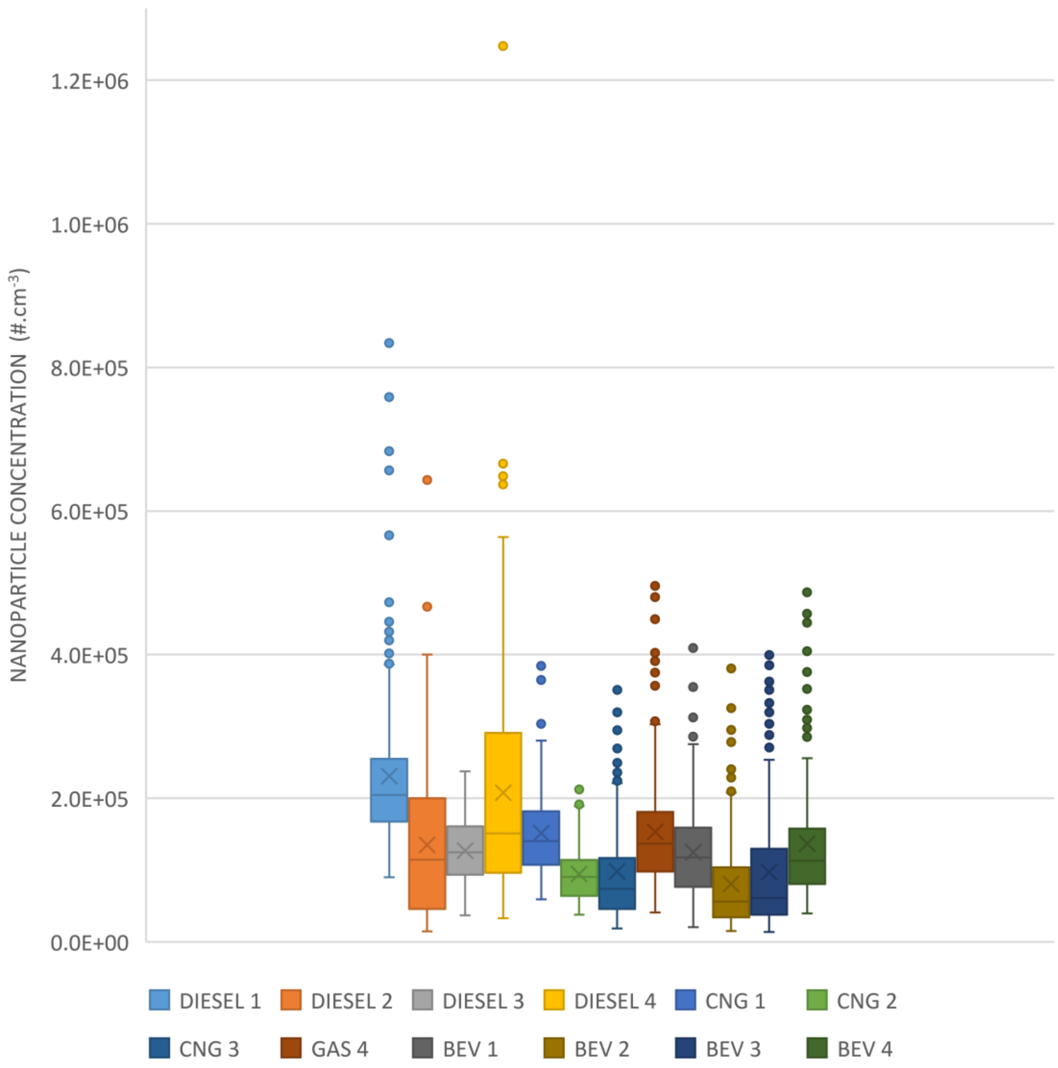

Fig.4 Nanoparticle concentrations for Diesel, Gas and electric bus technologies

Overall, these results provide important insights into the nanoparticle concentrations, nanoparticle diameter, and lung-deposited surface area associated with each bus technology.

4. Discussion

The findings of this study reveal important insights into the exposure concentrations of nanoparticles in different bus technologies. The results show that BEV buses exhibit lower nanoparticle concentrations compared to CNG and diesel buses (Tab.5). This finding is consistent with previous studies conducted in cities such as Arnhem, Netherlands, and Como, Italy, which have also reported higher UFP concentrations in diesel buses (Singh et al., 2016; Zuurbier et al., 2010). On the other hand, compressed natural gas buses and electric buses tend to have lower UFP concentrations (Ragettli et al., 2013; Morales et al., 2017; Knibbs et al., 2011).

These differences in nanoparticle concentrations can be attributed to the combustion characteristics and emissions profiles of each bus technology.

The average nanoparticle diameter was found to be greater in CNG buses compared to diesel and BEV buses (Tab.5). This observation is consistent with the understanding that different combustion processes and fuel characteristics can influence the size distribution of nanoparticles emitted by vehicles. For example, the combustion of natural gas in CNG buses can result in the production of larger nanoparticles compared to diesel combustion (Singh et al., 2016). Additionally, factors such as the engine design and emission control systems can also contribute to variations in nanoparticle size among different bus technologies.

Furthermore, the average lung-deposited surface area (LDSA) was lower in BEV buses compared to CNG and diesel buses (Tab.5). The LDSA is an important parameter that indicates the potential health impact of nanoparticles, as particles with larger surface areas have a greater potential for interaction with lung tissues. The lower LDSA observed in BEV buses suggests a potentially reduced health risk associated with nanoparticle exposure in these vehicles compared to CNG and diesel buses. However, it is important to note that other factors, such as the chemical composition and toxicity of the nanoparticles, should also be considered when assessing the health implications of nanoparticle exposure.

The findings of this study align with previous research conducted in different cities around the world. For example, studies conducted in Arnhem, Netherlands, and Como, Italy, have reported higher UFP concentrations in diesel buses compared to electric and natural gas buses (Singh et al., 2016; Zuurbier et al., 2010). Similarly, studies in Barcelona, Spain, and Beijing, China, have shown relatively low nanoparticle concentrations in electric buses (Moreno et al., 2015; Yang et al., 2021). These consistent findings across various cities indicate that the bus technology, along with other factors such as traffic conditions and urban air pollution levels, plays a significant role in determining nanoparticle exposure in public transportation systems. Also, the mode of transport, commuting route, and type of vehicles play influential roles in determining the levels of particulate matter exposure (Zuurbier et al., 2010).

It is worth noting that the relationship between nanoparticle diameter, concentration, and LDSA is complex and not directly proportional. The results of this study demonstrate that nanoparticle count and LDSA exhibit a proportional relationship across the different bus technologies (Table 6). However, the nanoparticle diameter does not follow a consistent pattern. This highlights the need for a comprehensive understanding of the factors influencing nanoparticle characteristics and their potential health effects. However, nanoparticle count and lung-deposited surface area show a proportional relationship across the different bus technologies (refer to Figg. 5-7).

Technology	Average Nanoparticle concentration (#.cm^{-3})	Average particle size (nm)	Average lung-deposited surface area (μm^2. cm^{-3})
BEV	108,519.4	35.2	191.6
CNG	121,904.9	42.4	273.9
Diesel	166,558.6	37.2	344.3

Tab.5 Average results per bus technology

Comparative	Average number (#.cm^{-3})	Average nanoparticle diameter (nm)	Average lung-deposited surface area (μm^2. cm^{-3})
BEV Vs Diesel	-41%	-10%	-48%
BEV Vs CNG	-27%	-18%	-39%

Tab.6 Comparison of the results per bus technology

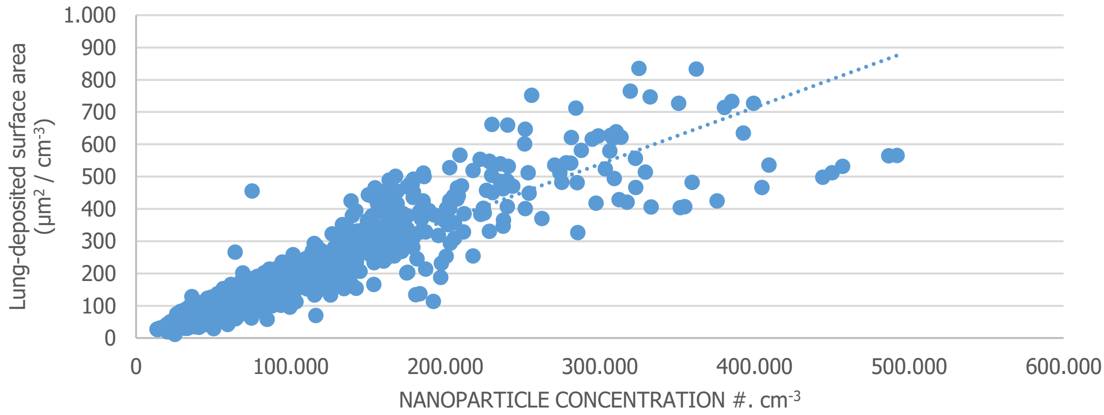

Fig.5 Nanoparticle concentration vs lung-deposited surface area in BEV buses

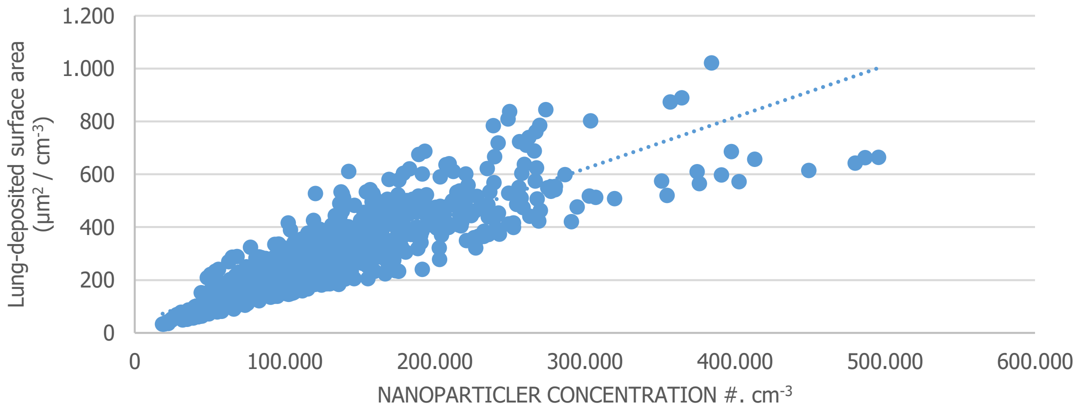

Fig.6 Nanoparticle concentration vs lung-deposited surface area in CNG buses

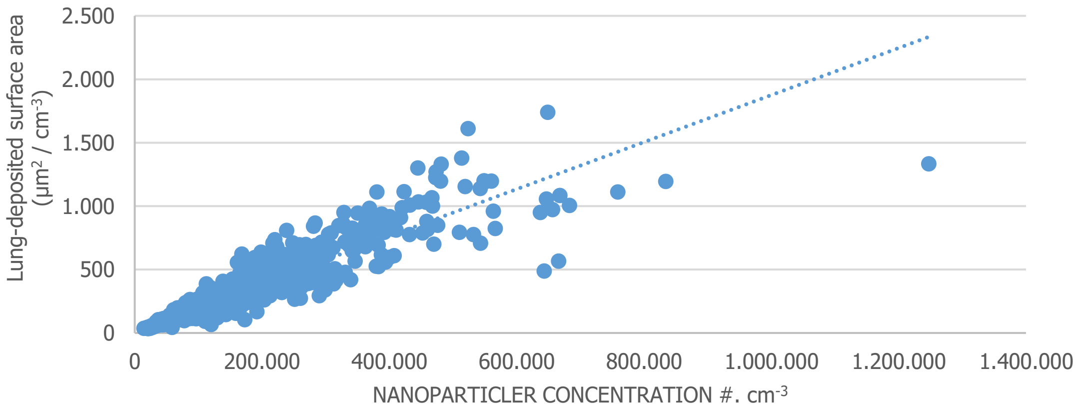

Fig.7 Nanoparticle concentration vs lung-deposited surface area in Diesel buses

The age of lubricating oil in diesel and CNG engines has been identified as a potential factor influencing nanoparticle concentrations (Singh et al., 2016). However, the results of this study did not show a clear direct proportionality between lubricating oil age and nanoparticle concentration per cubic centimeter for any of the bus technologies. This suggests that other factors, such as engine condition, maintenance practices, and driving conditions, may also contribute to the emission characteristics of nanoparticles in these buses. Further research is needed to explore the specific mechanisms and factors influencing nanoparticle emissions from different bus technologies.

While BEV buses generally exhibited lower nanoparticle concentrations on average, there were instances where the concentrations reached levels similar to CNG and diesel buses along the route. This variation can be attributed to factors beyond the bus technology itself, such as urban pollution, presence of other vehicles, and other local sources. Peaks in nanoparticle concentrations resulting from doors opening at bus stops indicate the influence of external factors on nanoparticle exposure. Similar findings have been reported in studies conducted in cities such as Barcelona and Beijing (Moreno et al., 2015; Yang et al., 2021). The "stop-start" nature of bus journeys and door openings can increase opportunities for air infiltration, even when windows are closed (Knibbs et al., 2011; Zuurbier et al., 2010). These findings emphasize the importance of considering external factors and localized conditions when assessing nanoparticle exposure in buses.

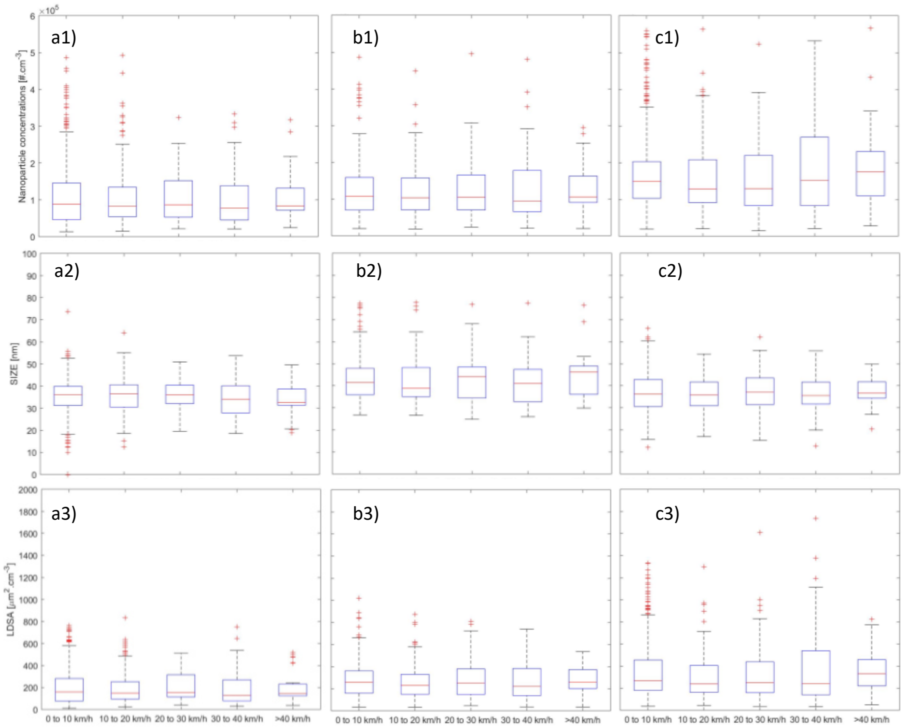

Fig.8 Nanoparticle concentration, average particle size and lung deposited surface area Vs. operating speed in a) BEV, b) CNG, and c) Diesel buses

The relationship between bus operating speed and nanoparticle characteristics was also investigated in this study (see Fig.8). Nanoparticle concentrations vs speed results indicate that there could be an optimal speed in to which less nanoparticles are emitted. Between 30 to 40 km/h there seems to be a reduction in nanoparticle concentration per cubic centimeter for BEV and CNG (Fig.ss 8 a1 and b1). For diesel buses a speed between 20 and 30 km/h seems to produce less particles (Fig.8 c1). Average particle size seems greater for CNG buses (Fig.8 b2) than for BEV or Diesel (Fig.ss 8 a2 and c2) but there is no evident dependency between size and speed. LDSA is much smaller inside BEV buses (Fig.8 c1) and between 30 to 40 km/h there seems be a reduction in LDSA for all technologies.

The particle levels in buses in this study were higher than in other cities, including Basel, Switzerland, (17 days of measurements between December 2010 and September 2011. The city, located in the Rhine valley (260 m above sea level), has about 190,000 inhabitants and has average temperatures of 3 °C – 6 °C in winter, and 21 °C–25 °C in summer. Residents primarily use public transport (52%), private car (18%), or bicycle (17%) for their daily commute to work), (Ragettli et al., 2013), Arnhem, Netherlands (capital of the province of Gelderland, located in the east of the Netherlands. Arnhem has about 150,803 inhabitants in 2014) (Singh et al., 2016) and, Beijing, China (capital of the Republic of China and one of the most populated cities in the world with 21,890,000 inhabitants in 2020, and dense traffic with more than 6 million vehicles) (Wang et al., 2022), Barcelona, Spain (Spanish city, capital of the Community of Catalonia, with a population of 1,636,732 inhabitants in 2021, is the second most populous city in Spain, measurements were made between October and November 2014 for 39 working days, with only one day with rain) (Moreno et al., 2015) the proportion of the results was only similar to studies in Milan, Italy (almost 3 million inhabitants) (Cattaneo et al., 2009) and Santiago, Chile (capital and main city of Chile, with 5,614 million inhabitants in 2017, and approximately 5.98 million registered vehicles) (Sirignano et al., 2018). The differences can result from many factors such as traffic conditions, bus technology, and urban air pollution concentration in the different cities, but also from bus ventilation (fans, air conditioning, open windows, and others). Comparisons with particle levels observed in other cities reveal variations influenced by multiple factors. The higher particle levels observed in this study compared to cities like Basel, Arnhem, Beijing, Barcelona, Milan, and Santiago can be attributed to differences in traffic conditions, bus technology, urban air pollution concentrations, and bus ventilation systems. These variations emphasize the importance of considering the specific context and local factors when assessing nanoparticle exposure levels.

5. Conclusions

This study provides valuable insights into the nanoparticle concentrations, sizes, and lung-deposited surface areas associated with different bus technologies. The findings support previous research indicating lower nanoparticle exposure in BEV buses compared to CNG and diesel buses. However, the complex relationship between nanoparticle characteristics, bus technology, and external factors highlights the need for further research to better understand and mitigate nanoparticle exposure in public transportation systems. Future studies should explore additional factors influencing nanoparticle emissions, such as engine conditions, maintenance practices, and driving conditions, to develop effective strategies for reducing particle exposure in buses. Furthermore, comprehensive assessments considering the chemical composition and toxicity of nanoparticles are necessary to fully evaluate the potential health impacts associated with nanoparticle exposure in different bus technologies. This study was the first to compare the exposure to traffic-related nanoparticles, inside three bus technologies: Diesel, CNG, and BEV, in Bogotá, a megacity in Colombia.

The concentration of nanoparticles per cubic centimeter in BEV buses is 27% and 41% lower than in CNG and diesel buses, respectively (Navarro et al., 2021). This reduction in nanoparticle exposure is significant as it can contribute to reducing the risk of health effects such as respiratory tract irritation, increased susceptibility to respiratory infections, and exacerbation of symptoms in individuals with chronic diseases. Moreover, the average diameter of nanoparticles in BEV buses is 18% and 10% lower than in CNG and diesel buses, respectively. Additionally, the average lung-deposited surface area in BEV buses is 39% and 48% lower than in CNG and diesel buses. This reduction in lung-deposited surface area is crucial as nanoparticles with smaller sizes have a greater potential for entry into the bloodstream, potentially affecting diseases related to the circulatory system (Navarro et al., 2021).

The analysis of the relationship between bus operating speed and nanoparticle characteristics shows that Diesel buses emit a greater number of particles per cubic centimeter and greater LDSA.whereas CNG buses have particles with grater average diameter. It also suggests that there could be an optimal operating speed to minimize number concentrations and LDSA for each bus technology and highlight the need for further investigation into the impact of operating speeds on nanoparticle characteristics.

In Colombia, as in many other countries, land-use regulations are often under the jurisdiction of autonomous municipalities. However, local governance tends to prioritize issues directly related to citizens' aspirations, leaving strategic concerns such as environmental considerations at the trans-municipal level outside the priority agenda (Howell-Moroney, 2008). The rapid motorization of cities has resulted in significant changes in urban conditions and the nature of inner-city areas. Traditional centralities have faced challenges, while new forms of centrality have emerged along corridors and strips around avenues and highways, concentrating various activities. This urban transformation, accompanied by sprawl and fragmentation, poses risks to environmental, economic, and social sustainability (Hernandez, 2012).

The right to an adequate environment for health and well-being necessitates the integration of sustainability variables in all processes of technological advancement. Therefore, the selection processes of bus technologies for public passenger transport in urban contexts must consider not only financial and technical factors but also analyze potential health risks to users and other stakeholders, as well as conduct environmental impact assessments (Hernandez, 2012). The alarming levels of nanoparticle exposure observed in diesel buses in this study, along with their widespread use in many megacities, highlight the urgent need for policymakers to prioritize improving bus transportation systems by transitioning from diesel to cleaner power sources.

Considering the characteristics of the population (more than 7 million inhabitants), vehicle density vehicles (more than 1,9 million additions to two-wheeled motorcycles), average travel distances, road infrastructure, and hourly demand for transport services, it is unlikely that travel times will decrease significantly in cities with similar characteristics. The observed reductions in nanoparticle concentrations with BEV buses can potentially decrease the health risks for users. This finding has important implications for public health policies and high-impact projects in major cities (Navarro et al., 2021).

Future studies should aim to confirm these results with new measurements conducted at different times of the year and under varied weather conditions. Comparative analyses should also be conducted to assess the performance of diesel, CNG, BEV, and other technologies for different types of buses, including small buses, articulated buses, and buses with more than two bodies. Additionally, research should be expanded to include private transport vehicles, taxis, trucks, and other possible applications such as delivery and last-mile transportation.

Other variables such as temperature, sound, vibrations, and external factors like doors opening, windows, and stops in areas with high pollution levels should be analyzed to gain a comprehensive understanding of nanoparticle exposure in buses. Furthermore, including the perceptions of bus users in future research would provide valuable insights into their experiences and perspectives.

The current global challenges, including climate change mitigation and reducing social inequalities, demand the integration of technological innovations into territorial contexts to foster the development of smart and sustainable cities. This requires the definition of strategies and concrete actions that support the evolution of urban and territorial systems, ultimately contributing to the achievement of the sustainable development goals (SDGs) outlined in the United Nations' 2030 agenda.

The findings of this study provide valuable information for planners, decision-makers, and investors responsible for improving transportation systems and reducing social disparities through technological advancements. The comparative data on bus technologies presented in this study can serve as a decision-support tool when selecting the appropriate bus technology to prioritize the health and well-being of users. By leveraging natural resources and energy efficiency, transportation integration can become a platform for regional development, leading to the creation of wholesome, responsible, and sustainable cities that ensure a high quality of life for all populations.

In conclusion, the measurement processes of the three bus technologies used in this study demonstrate that BEV buses exhibit a positive variation in nanoparticle exposure levels compared to CNG and diesel buses, contributing to improved health outcomes for transport system users. The findings emphasize the importance of incorporating sustainability considerations and health impact assessments into the decision-making processes surrounding bus technology selection and urban development. By aligning technological advancements with the goals of climate change mitigation and social equality, cities can pave the way for a more sustainable and resilient future.

Authors contribution

All authors contributed to the conception and design of the study. Vargas did the preparation of the material, the data collection and the analysis. The first manuscript version was written by Vargas, the initial review and corrections to the data analysis were made by Durán and Galvis. Data corrections and analysis improvements were made by Bernal and Galvis; all authors commented on earlier versions of the manuscript. All authors read and approved the final manuscript.

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The authors report there are no competing interests to declare.

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