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Research article

Addressing air quality challenges: Comparative analysis of Barcelona, Venezuela, and Guayaquil, Ecuador

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ABSTRACT

This study presents a willingness-to-pay (WtP) questionnaire that was designed, validated, and applied to assess perceptions of air quality and self-reported health in two middle-income South American cities: Barcelona and its neighboring cities (Venezuela) and Guayaquil (Ecuador). These cities lack air quality monitoring and control measures. The questionnaire is a reliable tool to assess air quality based on citizens' perceptions, and the results reveal that both populations perceive low air quality and accurately identify emission sources and air pollutants (industrial emissions and particulate matter in Barcelona and vehicular emissions and carbon monoxide in Guayaquil).

The study also evaluated the efforts made by both cities to improve air quality using the United Nations Environment Programme to strengthen air quality in South America. Based on this evaluation, strengths were identified for enhancing air quality in both cities. The study finds that in Barcelona and its surroundings, investment is needed to improve urban transport, waste management, and update the environmental legislation regarding air quality at the national level. In contrast, Guayaquil has already taken some measures to improve air quality, but more investment in public transport and measures to lower vehicle emissions are needed.

1. Introduction

Air pollution is the foremost environmental health hazard in Latin America, affecting over 150 million people living in urban areas with air quality that exceeds World Health Organization (WHO) guidelines [1]. The U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) for outdoor concentrations of five criteria pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, particulate matter (PM), and sulfur dioxide (SO_2) [2].

PM can originate from both natural and anthropogenic sources, with the primary anthropogenic sources being combustion processes, such as those associated with industries, transportation, and open waste burning. PM can be categorized into different size fractions: total suspended particles (TSP) with an aerodynamic diameter of $\leq$100 μm, PM_{10} with an aerodynamic diameter of $\leq$10 μm, and $PM_{2.5}$ with an aerodynamic diameter of $\leq$2.5 μm.

PM has gained significant attention due to its impact on global health. Extensive research has linked PM_{10} and $PM_{2.5}$ to chronic and

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acute health effects, with $PM_{2.5}$ being the main driver of this health burden [3,4]. A systematic analysis of air quality data from South American cities from 2010 to 2017 revealed that 11 cities had PM_{10}-annual levels between 25 and 120 μg m^{-3} and 8 cities had $PM_{2.5}$-annual levels between 13 and 34 μg m^{-3}, surpassing WHO guidelines [5]. The WHO deems PM_{10}-annual levels of 15 μg m^{-3} and $PM_{2.5}$-annual levels of 5 μg m^{-3} as safe thresholds for human health [4]. Compiling air quality data in South American is challenging due to issues like data unavailability, limited public release, and the high cost of regular monitoring networks. This hinders the inclusion of certain cities in air quality studies.

Cities in South America lacking systematic air pollution data but suspected of compromised air quality provide an intriguing focus for our study. Our criteria for selecting cities included those with mixed urban-industrial land use, experiencing unplanned growth, and showing signs of pollution through public complaints. Operational variables such as accessibility, local talent, resources, and author familiarity also influenced our choice of study locations. Barcelona and surrounding cities in Venezuela, as well as Guayaquil in Ecuador, met these initial criteria. Additionally, they are medium-sized cities, with tropical climates, distinct dry and rainy seasons, cultural similarities, and where a limited yet pertinent air quality research has been conducted.

For Barcelona and surrounding cities, a study modeling solely on emissions from major industries, neglecting those from small industries or the vehicular fleet, revealed that residents have faced persistent risk episodes of PM_{10} and SO_2. The yearly average concentration of both pollutants surpassed the WHO's recommended limits [6]. As of present, no study has indicated an improvement in air quality conditions.

For the city of Guayaquil, a more recent study identified compromised air quality, with $PM_{2.5}$-24 h exceeding the WHO's recommended threshold for 48 % of the measurement period [7]. Additionally, a transportation emissions study estimated emissions from the city's transport fleet in 2018, indicating 237.1 kt of CO, 28.5 kt of volatile organic compounds, 46.4 kt of NOx, 7.7 kt of PM_{10}, 0.70 kt of SO_2, and 4549.7 kt of CO_2 [8].

In regions where long-term monitoring air quality data is lacking or significantly limited, alternative sources such as online platforms utilizing modeling techniques or local sensors become an alternative (See **Supplemental Information** S3) [9–13]. While these type of source offer provisional data, it's essential to acknowledge they not provide the same level of accuracy as comprehensive monitoring systems.

The cities in question are of intermediate size and characterized by significant industrial presence and heavy vehicular traffic. Despite conducting extensive online searches, the authors were unable to find evidence of ongoing air pollution monitoring or public campaigns aimed at raising awareness about the health hazards associated with residing in areas with poor air quality.

To tackle the effects of air pollution in cities with scarce data, alternative approaches are needed that involve the affected population and encourage local governments to act. Environmental economics approaches can provide useful tools for this purpose [14].

The contingent valuation method (CVM) is an economic tool that simulates a market to estimate the value of a good or service that is not traded in formal markets. It is particularly useful in cases where direct market transactions are not feasible, such as in valuing the benefits of air pollution reduction. The CVM has been widely used to quantify the benefits of improving air quality in terms of monetary value, as shown in various studies conducted globally, including Africa, Europe, the Americas, and Asia [15]. The continued use of the CVM for air pollution research shows its enduring worth in cities where direct pricing is difficult.

The contingent valuation method (CVM) aims to measure the willingness-to-pay (WtP) of the population for a hypothetical scenario. This is done via questionnaires that gather information on variables that are thought to influence WtP, such as perception, demographics, and health. It is crucial to ensure that questionnaires adhere to the best practices of both the CVM and the general methodological requirements for designing such instruments.

The design of an air pollution WtP questionnaire should also consider the local/regional context. For South America, in 2017, the United Nations have proposed ten challenges to strengthen air quality based on governmental actions [16]. These challenges provide a context for air pollution in this region. They propose actions in the industrial sector, transport sector, open waste burning, and revision, update, and compliance of the environmental legislation. Given the lack of information on monitoring that reveals the air quality in the cities of South America, a first step would be to know the perception of the population about it and its sources. A well-designed and validated WtP questionnaire can effectively capture the current situation about the perception of people, and where cities are located with respect to the challenges proposed by the United Nations.

Our aim is to design, validate, and apply a WtP questionnaire for improving air quality in two middle-income South American cities (Barcelona, Venezuela and Guayaquil, Ecuador) that allows them to better understand their air quality based on the perception of respondents, and to qualitatively assess the progress made in addressing challenges to strengthen air quality in these cities.

2. Air quality: the willingness to pay questionnaire

The questionnaire aims to determine the WtP for the improvement of air quality contaminated with particulate matter in middle-income South American cities with mixed land use, considering the effect of air pollution on human health. The authors ensured a clear and concise wording of the questionnaire and strict control of biases. The questionnaire's design is carried out in several stages:

- Design of the pre-questionnaire
- Validation of the questionnaire
- Application of the pilot test
- Design of the final questionnaire
- Application in the field

2.1. Pre-questionnaire design

The pre-questionnaire was designed in 2015, in Venezuela, using successful questionnaires from other authors for studies of willingness to pay for environmental goods [17–19]. To avoid biases of distrust towards the promoter of the questionnaire, it was proposed to begin with an introductory text with information on the nature and purpose of the research. To avoid biases in the interpretation of the data during the application of the questionnaire, a logical expository sequence was used for both the researcher and the respondent, especially in the sections that collect subjective information, opinions, or evaluations [20]. The questionnaire was designed to be applied in person to adults of both sexes, by means of non-probabilistic intentional sampling, anonymously, confidentially, and voluntarily [21]. The established requirement is that the respondent lives and/or works in the area where the questionnaire is applied or spends at least 4 h a day in that area.

The pre-questionnaire was structured into four sections:

- Section A: Perception of air quality. This section measures survey participants' perceptions of air quality, emission sources, and criteria pollutants present in the air. Diseases associated with air pollution are also listed. It was structured by 10 questions.
- Section B: Willingness to pay for the improvement of air quality. This section formulates a contingent scenario. The argument is based on proposing improvements in air quality by reducing industrial emissions of PM through control devices in PM emissions chimneys, mentioning the social and health benefits of this reduction. A "Fund" will be created to subsidize the installation of control devices in PM emissions chimneys, with contributions from polluting industries and civil society. The questionnaire asks if the participant is willing to pay for this improvement, and if so, the maximum amount they are willing to pay. The industry's contribution percentage to the Fund is also established through consensus. Two questions in closed polytomous format are presented to determine the entity responsible for collecting and administering the money. Negative responses to willingness to pay are measured through 9 options, differentiating between protest and justified responses. Protest responses occur due to distrust of the administration or collection, lack of responsibility or attachment to the good, lack of resources, or knowledge about the subject. It was structured by 6 questions.
- Section C: Socioeconomic factors of the survey participant. The objective is to know the sociodemographic conditions of the survey participants. It was structured by 7 questions.
- Section D: Health status and habits. The objective is to inquire about the survey participant's perception of their respiratory and cardiovascular health. The survey participant is asked to self-assess their respiratory health. It was structured by 9 questions.

2.2. Pre-questionnaire validation

A panel of seven experts in different areas: environmental economics, atmospheric pollution, contingent valuation, research methodology, sociology, and respiratory health, evaluated the pre-questionnaire, analyzing its coherence, content, and compliance with ethical and professional research codes. Overall, they found the questionnaire to be coherent and relevant, with the inclusion of a health perception section deemed appropriate. However, the experts suggested general changes to the writing style, such as making the introduction more cordial. They also recommended using colloquial language in the contingent scenario, rather than relying on technical terms, to make the writing clearer and more engaging.

The experts praised the contingent scenario as realistic and well-structured but advised reducing the number of technical terms used. They also recommended measuring the respondent's socio-economic status, which was incorporated into the questionnaire using the Graffar-Méndez Castellano methodology [22].

The experts proposed adding a question in Section A about the survey taker's environmental care. They also advised against relying on the respondent's memory for questions about disease and suggested changing the subjects to include family members or friends who live together. Additionally, they recommended changing the subject of questions about smoking and place of work to the person who suffered from the disease, rather than the survey respondent.

Some of the changes were incorporated, while others were deferred for evaluation during the pilot application. The experts did not identify any ethical violations in the social sciences. The result of this stage is the pilot questionnaire, which will be used to gather data on willingness to pay for air quality improvement in the area.

2.3. Pilot test

The pilot test assesses the questionnaire's validity, difficulty, and duration before its final application and uncovers potential reasons for non-responses, such as lack of interest, anonymity distrust, or time constraints. The pilot questionnaire undergoes validation with a smaller sample size in a location that mirrors the characteristics of the region where the final questionnaire will be administered. The pilot test was conducted in a middle-income Venezuelan town with mixed industrial and residential land use, covering 182 km^2, accommodating 209,987 residents, and hosting 700 medium and small industries [23].

Different techniques are used to evaluate the validity and internal consistency of each section of the questionnaire. Internal consistency indicates whether applying the same instrument repeatedly to the same subject at different periods produces equivalent results [24]. Statistics such as the Pearson correlation coefficient (r) and Cronbach's Alpha coefficient assess the internal consistency of each section, whereas techniques for CVM questionnaires validate section B [25]. The coherence of responses given during the pilot test evaluates section C qualitatively.

It was discovered in section A that some questions measured the same variable, resulting in the need to revamp the way variables were measured. The internal consistency of section A was good, with a Cronbach's Alpha coefficient of 0.87, which exceeds the 0.70 threshold typically considered satisfactory for most applications [26]. Section D, on the other hand, required restructuring completely as conflicts, writing, and structural errors were identified, and more than 30 % of the surveyed did not respond to questions requiring memory efforts [27]. In the willingness to pay section of the 50 completed questionnaires, 48 were valid, and 38 showed a positive willingness to pay (WtPpositive). Two were discarded because they did not answer the question of maximum willingness to pay (WtPmax), resulting in 36 questionnaires with WtPmax positive. Ten questionnaires with WtPnegative (WtP = 0) were analyzed to distinguish between "real zeros" and "protest zeros" with one presenting a justified answer and the remaining nine considered "protest zeros". A total of 37 individuals represented the hypothetical market, with 36 having WtP>0 and 1 with WtP = 0. These WtPmax values will represent the BID in the final questionnaire, with the frequency of assigning a BID value in the final questionnaire proportional to the number of times that WtPmax value is repeated in the pilot test.

Qualitative evaluation of section C revealed language and format errors and some wording that may have led to a lack of understanding. The wording and content of some questions were modified, and the survey participants' comments on language were considered. The survey participants successfully answered the questions measuring socioeconomic status through a continuous variable according to the Graffar method. Overall, the survey participants were receptive to the questionnaire.

2.4. *Final questionnaire design*

The final questionnaire underwent revisions based on expert feedback and the analysis of pilot test results. Four sections were maintained from the pre-questionnaire, while changes and suggestions were incorporated to improve the overall structure and content.

For Section A, four questions were removed: one question regarding the respondent's perception of air pollution was replaced by an option for identifying potential sources of emissions, and three implicit questions were integrated into others. A new question was added to assess the importance respondents place on environmental conservation and protection. Table 1 presents details on the seven questions included in the final version of Section A of the questionnaire.

In Section B, the pilot test achieved consensus on the administrator of the Fund, which was included in the final questionnaire. The questionnaire inquired about the percentage of industry contributions to the Fund and who should collect them. Although the pilot test established the entity responsible for collecting money for the Fund, it did not determine the percentage that should be contributed by the industrial sector. Table 2 outlines the structure of Section B in the final questionnaire, which consists of two open-ended dichotomous questions. The first question asks whether respondents are willing to pay a predetermined amount that corresponds to the BID, while the second question inquires about their maximum willingness to pay (WtPmax). The answers to these questions establish the WtPpositive and WtPnegative.

For Section C, we made corrections to the form, language, and order of the questions, incorporating four questions to measure the

Table 1
Structure, variables, and format of Section A of the final questionnaire.

Section A. Perception of air quality				
Question	A1. Events generated by air pollution	A2. Identify emission sources	A3. Personal actions to improve air quality	A4. Identify air pollution diseases
Response options	Difficulty breathing Eye/throat irritation Smoke Smells Visibility lack None/Not known	Industrial stacks Vehicle traffic Rubbish burning Street dust Other None/Not known Air is not polluted	Use public transport Buy electric vehicle Use less electricity Emission control fee Lead pollution strikes Do not burn waste Other	Cough Allergies Asthma Eye/throat irritation COPD Bronchitis Pneumonia Stroke Lung cancer None/Not known
Question type	Multiple choice			
Handling	Sum of number of options chosen			
Variable Type	Nominal			

Question	A5. Identify air pollutants	A6 Considers that there is PM in the air	A7. Declaration of the importance of conservation and protection of the environment
Response options	PM CO SO_2 NOx O_3	Definitely Yes Probably Yes Probably No Definitely No	Very important Important Not very important Not important at all
Question type	Multiple choice	Single choice	
Handling	Sum of number of options chosen	Likert scale	
Variable Type	Nominal	Ordinal	

Table 2
Structure, variables, and format of Section B of the final questionnaire.

Section B. Willingness to pay to improve air quality			
Question	B1. Willingness to pay the BID for the creation of a fund to invest in lowering air pollutant emissions	B2. What would be the most you would be willing to pay?	B3. What percentage of the total Fund should the industries contribute?
Response options	Yes No	o to ∞	55–95 %
Question type	Single choice	Open-ended	Single choice
Handling	A BID is offered	Questions B2 and B3 have no handling because they're not variables in the analysis	
Variable Type	Nominal		
Question	B4 Identify the entity collecting the money for the fund	B5 If the answer to B2 was "non-payment", identify the reason for non-payment	
Response options	The electricity companies A new autonomous agency	I am not interested in contributing to the air quality. I do not have the financial resources to pay I am suspicious of how the money will be handled. This expenditure is the sole responsibility of the industry. This expenditure is the sole responsibility of the State It is not necessary to improve air pollution control. It is unfair for me to pay for what someone else pollutes. The air is clean I don't know the subject Another	
Question type	Single choice		
Handling	Questions B4 and B5 have no handling because they're not variables in the analysis		
Variable Type			

socioeconomic variable using Venezuela's Graffar's methodology. Table 3 shows the details for the eleven questions in section C of the final questionnaire.

In Section D, we removed four questions related to health details and expanded the inquiry on who suffered from the disease to include both respondents and their close relatives. Table 4 displays the final six questions included in this section.

Once the final questionnaire was applied, we recalculated the Cronbach's Alpha statistic to check that the internal consistency of the questionnaire is maintained despite the changes made in sections A and D.

3. Assessing the willingness to pay for air quality improvement in two South American cities

We applied the final questionnaire first in Barcelona and its surrounding cities on the northeastern coast of Venezuela, and secondly in Guayaquil in the northern coastal region of Ecuador. These cities share common characteristics of unplanned urban growth and a strong industrial presence, resulting in overlapping industrial and urban areas. In addition, there is a lack of government environmental monitoring, open access reporting, and public policies on air quality.

Table 3
Structure, variables, and format of Section C of the final questionnaire.

Section C. Socioeconomic Factors of the Respondent				
Question	C1 Salary range	C2 Level of studies	C3 Time spent in city	C4 Marital status
Response options	Five salary ranges were available	None Primary Secondary Bachelor Masters PhD studies	<4 h 4< x < 8 h 8< x > 12 h; >12 h	Single Married Widowed Divorced Partnered
Question type	Single choice			
Handling	Numerical hierarchy			Dichotomized
Variable Type	Interval			Nominal
Question	C5 Gender	C6 Age	C7 Number of children	C8 Socioeconomic status
Response options	Male Female Non-binary	o to ∞	o to ∞	Four options were available
Question type	Single choice	Open-ended		Single choice
Handling	Dichotomized	The number taken is		Numerical hierarchy
Variable Type	Nominal	Continuous		Interval

Table 4
Structure, variables, and format of Section D of the final questionnaire.

Section D. Self-reported health and habits			
Question	D1. Do you consider air pollution a risk factor for your health?	D2. How do you rate your respiratory health?	D3. In the past year, have you or anyone you live with experienced any of the listed respiratory or cardiovascular diseases?
Response options	Definitely No Probably No Definitely Yes Probably Yes	Very good Good Bad Very Poor	Cough Allergies Asthma Eye/throat irritation COPD Bronchitis Pneumonia Stroke Lung cancer
Question type	Single choice		Multiple choice
Handling	Likert scale		Sum of number of options chosen
Variable Type	Ordinal		Nominal
Question	D4 Number of times the disease stated in the previous question has been experienced	D5 Does the person who experienced the disease smoke?	D6 Does the person who experienced the disease work in a polluting industry?
Response options	o to ∞	Yes No	
Question type	Open-ended	Single option	
Handling	Choose the diseases you have suffered from and the number of times you have suffered from them.	Dichotomized	
Variable Type	Continue	Nominal	

Our study aligns with the United Nations Environment Programme for the Promotion of Air Quality (UNEPPAQ) of 2017 and its proposed actions to enhance air quality in South American cities [16]. UNEPPAQ's ten proposed actions are organized into four major sectors: industrial activities, road transport, open burning of waste, and legislative efforts. Our questionnaire incorporated questions related to UNEPPAQ's proposed actions on industrial activities, road transport, and on the open burning of waste to assess residents' perceptions of air quality in the region.

3.1. Barcelona and its surrounding cities, Venezuela

Barcelona and surrounding cities (Píritu, Puerto Píritu, Puerto La Cruz, Lechería, Guanta) are located on a coastal strip that is 100 km long and covers an area of 2,897 km^2 (see Fig. 1). They have a combined population of approximately 1.09 million inhabitants [28]. Urban development in Barcelona is concentrated on the coastal plain and characterized by a disorderly layout, scarce urban green areas in these cities, and insufficient communication routes to accommodate current vehicular traffic needs. Land use is mixed, with urban areas bordering heavy industries in these cities [6]. The climate in this region is typical of an intertropical zone, with the temperature remaining stable throughout at 26 °C (23–32 °C) the year and the relative humidity ranging from 65 to 95 %, influenced by the rainy season. Precipitation in the area follows a distinct dry season and a rainy season [29].

There are nine petrochemical industries operating in an industrial complex between Barcelona and Puerto Píritu, while a cement plant and oil refining industry are found between Puerto La Cruz and Guanta. These industries emitted a total of 4,790 t per year of TSP and 8,376 tons per year of SO_2 in 2010, according to an emission inventory [30]. Sampling data of 24-h average SO_2 concentration between 2004 and 2006 indicated that SO_2-24 h exceeded the threshold recommended by the WHO over 57 % of the time. Furthermore, sampling data between 1997 and 2009 of TSP-annual at four stations in those cities showed that the annual TSP value regulated by Venezuela has been exceeded since 1998 [30]. Modeling of the dispersion of TSP and SO_2 emissions from the eleven industries indicated that industrial emissions recurrently impact urban areas, posing a health risk to the population [6]. When exploring alternative data sources for $PM_{2.5}$ concentrations in these cities, the apparent annual average $PM_{2.5}$ for the 2000–2010 decade is around 10 $\mu g\ m^{-3}$ (**Supplemental Information** S3). The most recent available measurements and reporting from monitoring stations for these cities, where done during 1997–2010 (data not publicly available) and suggests that the $PM_{2.5}$ annual average for that decade might be 24 $\mu g\ m^{-3}$ (**Supplemental Information** S3). This value is five times higher than the current WHO recommendation considered protective for a population. The difference between these data points introduces uncertainty. This highlights a broader issue of limited current information availability for the country.

Urban vehicular traffic in these cities is significantly congested, particularly during peak hours and rainy seasons, due to high vehicle density and insufficient road maintenance. The National Institute of Statistics reported around 250,000 registered vehicles in these cities in 2011, with many exceeding ten years of age [31]. The outdated public transport system, mainly consisting of buses, exacerbates the problem, as there are limited alternative transportation options available [32].

The authors could not find any systematic, official updated information on the levels of air pollution in the area or on campaigns

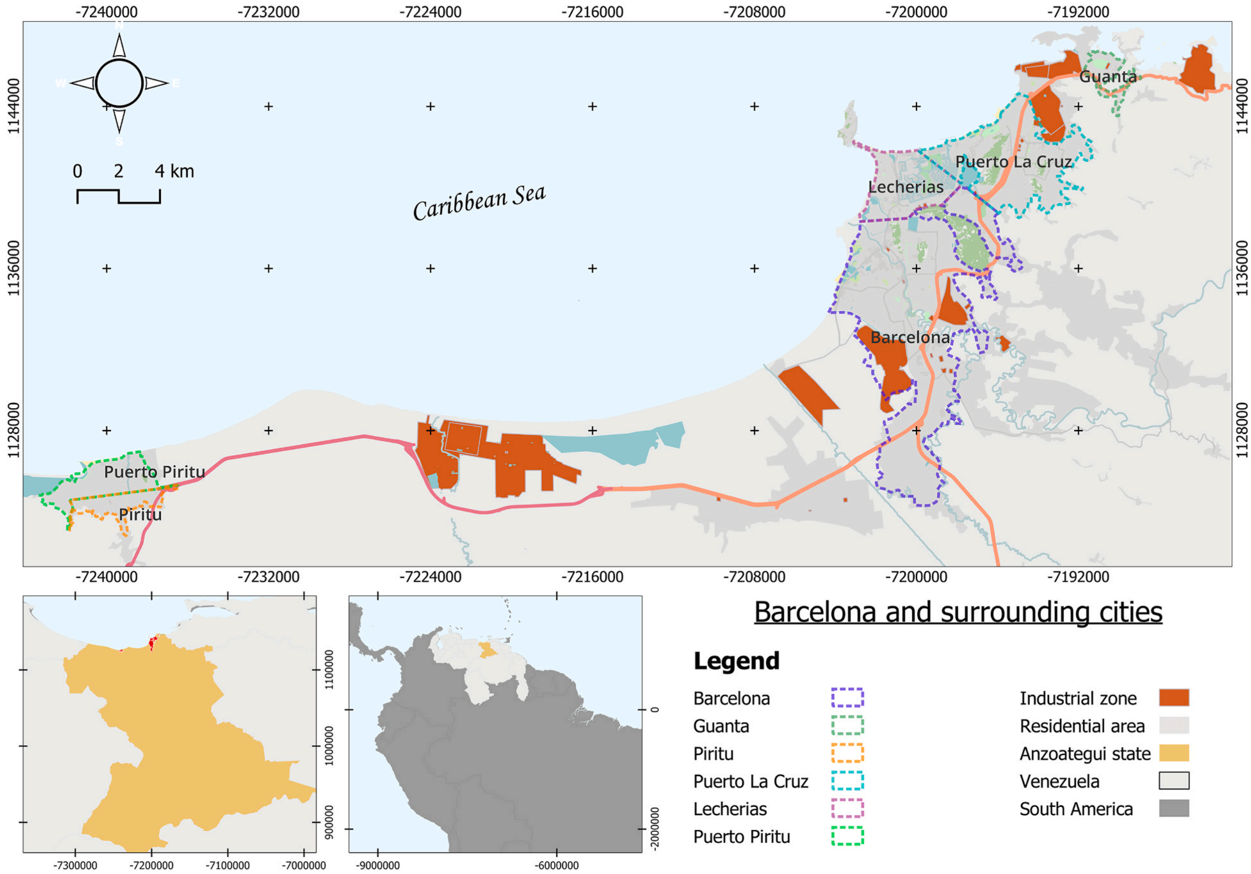

Fig. 1. Location of Barcelona and its surrounding cities, Venezuela.

informing the population about the risks of living in highly polluted areas. Since 2002, citizens have filed complaints with state agencies, categorizing this region as polluted. Air quality regulations in Venezuela have not been updated since 1995 [33].

The city of Barcelona and its surrounding areas mostly rely on two fossil fuel-fired thermoelectric power plants and a small portion from hydroelectric power from the national electricity system for their electricity supply [34]. While information on solid waste management in Barcelona and its surrounding cities is scarce, a report from the non-governmental organization Vitalis, indicates that about 85 % of solid waste in the country ends up exposed to the open air without proper treatment, and there are no incentives to promote recycling [35].

The WtP questionnaire was administered in 2015 to a sample of 384 people from Barcelona and surrounding areas. The survey population was composed of 40 % men and 60 % women, aged between 18 and 76 years, with an educational level ranging from low to technical-university, income levels between 38 and 63 USD. $month^{-1}$, with a weighted average salary of approximately 52 USD. $month^{-1}$. The Graffar method was used to stratify the survey population into socioeconomic strata, with 6.2 % in Stratum A, 46.1 % in Stratum B, 24.9 % in Stratum C, 20.6 % in Stratum D, and 1.6 % in Stratum E (where A is the highest stratum and E is the lowest) [36].

The Cronbach's alpha statistic was re-evaluated using the survey results. Section A scored 0.75 and section D scored 0.73, indicating acceptable reliability. Although the Pearson correlations revealed no redundant questions in sections A and D ($r < 0.90$), it was recommended to remove questions A6 and A7 (Table 1) as they behaved like a constant. After removing these questions, the Cronbach's alpha coefficient increased to 0.83. Out of 321 respondents, 259 declared positive WtP, while 62 revealed negative WtP (57 response-protest and 5 response-justified). Logistic analysis indicated a WtP of 1.50 USD. $month^{-1}$, equivalent to 2.9 % of their average monthly salary. The hypothetical market consisted of 264 individuals. The Fund's total investment would be around 57 million USD. $year^{-1}$ [36].

3.2. *Guayaquil, Ecuador*

Guayaquil is the largest city in Ecuador, with an estimated population of 2.7 million people [37]. It is near the Pacific coast of the country's coastal region (see Fig. 2). The city has an area of 344.5 km^2 and a flat topography that ends at the Pacific Ocean. The climate is stable, hot, and humid throughout the year, with median absolute maximum temperature of 24 °C s (ranging between 156 and 307 °C) and relative humidity levels greater than 60 %.

The city has many industries, including cement plants, quarries, food, chemical, and asphalt industries, thermal power plants, and a maritime port. The land use is mixed, with urban and industrial zones coexisting without differentiation of spaces [38,39].

Guayaquil has a well-developed public transport system that includes buses, bus rapid transit, taxis, motorcycle taxis, and a cableway. As of 2018, there were 450,000 registered vehicles in the city with an average age of 12.2 years [8]. Approximately 65 % of trips are made in private vehicles with diesel or gasoline engines, while buses and taxis mostly use diesel [8]. Public transport vehicles such as buses are often not well-maintained, leading to higher levels of emissions than would be expected from newer and properly supported vehicles [38]. Although the city has implemented measures such as mandatory vehicle inspections and restrictions on the circulation of vehicles with high emissions, only 4.3 % of the bus fleet and 1.1 % of the truck fleet have EURO III emission control technology [8]. Congestion and heavy traffic are persistent issues, especially during peak hours in the city center and on major thoroughfares.

An inventory of emissions from vehicular transport in Guayaquil estimates that 7,700 t of PM_{10} and 700 t of SO_2 were emitted in 2018 [8]. Previous reports estimated that 65 % of flue gas emissions came from the transport sector, 21 % from thermoelectric plants, and 14 % from the industry sector, and noted that Guayaquil lacked a permanent air quality monitoring network [39,40]. The 2012 report estimated that total PM_{10} emissions were 4,500 t and SO_2 emissions were 700 t, indicating a deterioration in air quality over the last 10 years. A recent study monitored $PM_{2.5}$-24 h concentrations at four landmark sites in Guayaquil, revealing that the WHO threshold of 2021, for $PM_{2.5}$-24 h was exceeded on 48 % of the days measured [7]. When reviewing alternative data sources for $PM_{2.5}$ concentrations (**Supplemental Information** S3), the projected annual average $PM_{2.5}$ for the 2000–2010 decade falls within the range of 6–20 μg m^{-3}. Deployed low-cost sensors in different urban locations show annual averages for 2021 and 2023 at 13 μg m^{-3} [11]. These values are somewhat aligned but uncertainty remain. The trend implies a potential threefold increase from the annual WHO guideline of 5 μg m^{-3}. The finding highlights the need for official, systematic, and publicly available information on air pollution and its associated health risks in the city.

Although Ecuadorian environmental legislation is one of the strictest in Latin America [33], local governments are responsible for implementing and monitoring air quality and vehicle inspections. Solid waste generation in Guayaquil is 0.58 kg. $inhabitant^{-1}$. day^{-1}, and the waste is collected door-to-door without sorting, then sent to landfills [41,42]. Recycling in the city is mainly informal, and “recyclers” are responsible for sorting and selling useable waste to factories. However, local policies and incentives for recycling and proper waste management have yet to be implemented.

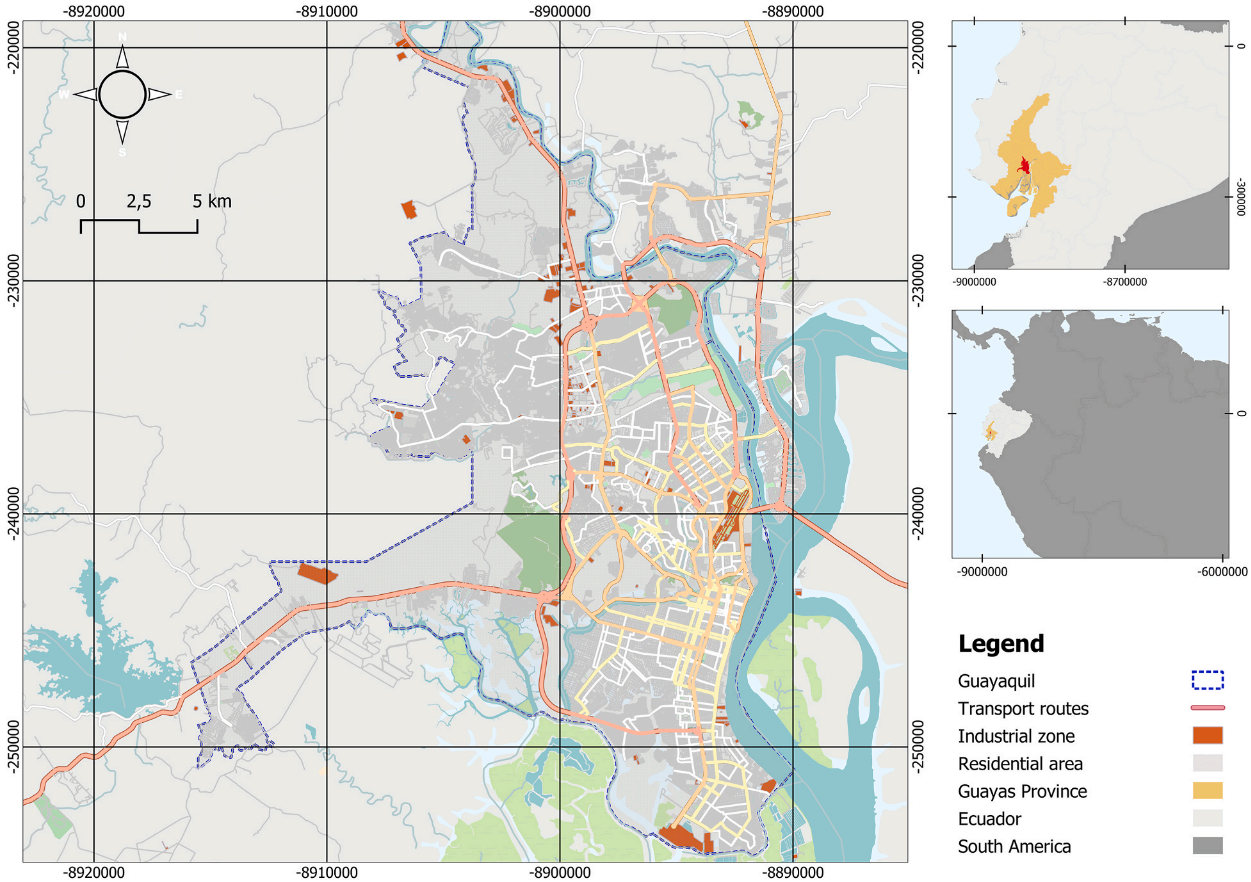

Fig. 2. Location of Guayaquil, Ecuador.

The WtP questionnaire was adapted for the Guayaquil context by making changes to the language and format of the questionnaire based on a pilot test conducted with 55 people in polluted locations identified by the Air Quality Management Plan [40]. The final questionnaire was administered to a sample of 272 individuals. Among the respondents, 69 % were willing to pay for improvements in air quality, while 31 % expressed negative sentiment towards payment, with 30 % protesting payment. The estimated WtP was approximately 4.15 USD per month, representing 0.75 % of the surveyed population's average monthly salary (550 USD per month). The fund for subsidies, including industry and population contributions, was estimated to be around 501 million USD per year [43].

3.3. Respondents' willingness to pay

The contribution value for air quality improvement in Guayaquil was estimated to be 8.7 times greater than that in Barcelona, totaling approximately 501 million and 57 million USD per year, respectively. At the time of the surveys, the population of Guayaquil was 4.7 times greater than that of Barcelona and surrounding cities. The minimum income level in Ecuador was higher than in Venezuela, at 375 and 34 USD per month, respectively.

To compare the WtP obtained in both case studies, we used the ratio between the WtP obtained and the average monthly salary of the respondents, expressed as a percentage (%WtPnormalized) [36]. The %WtPnormalized is 2.9 % for the Barcelona and surrounding cities case and 0.75 % for the Ecuador case, indicating that the population of Barcelona and surrounding cities has a higher WtP for air quality improvement.

To investigate the variables that may influence WtP, we compared the means of the values assigned to self-reported health (question D2, Table 4) using the t-Student statistic. The mean for the Barcelona and surrounding cities case is higher, showing that respondents in the Barcelona case reported worse self-reported health states than those in the Guayaquil case (μBarcelona = 2.46; μGuayaquil = 2.15 with $t = -5.46$; $p < 0.00$).

3.4. Pollution perception and self-reported health

Table 5 displays the Pearson correlation between air pollution perception (variables A1-A5, Table 1) and self-reported respiratory health (variables D1-D3, Table 4) for the Venezuelan case study (Barcelona and surrounded cities). The results showed moderate to low correlations ($p < 0.05$). Respondents who perceived more pollution (questions A1-A5) tended to report worse respiratory health (questions D1-D3). Those who perceived non-polluted air (option A2.8) reported positive health status.

Fig. 3-a shows that most respondents in both cities perceived pollution. However, more Guayaquil respondents reported not perceiving pollution (Probably-No). Fig. 3-b shows that most respondents in both cities reported good health status. In Barcelona, this could be due to respondents prioritizing other pressing issues related to their socioeconomic crisis [44–46].

In the questionnaire of residents of Barcelona and surrounding cities, 97 % identified at least one of six proposed emission sources (variable A-2; Table 1). On average, two emission sources were selected. The industrial sector was the most frequently selected source, followed by the transportation sector and open waste burning. In Guayaquil, 99 % of respondents identified at least one emission source, with an average of one source selected. The transportation sector was the most selected source, followed by the industrial sector. Open waste burning was not selected.

In both cities, 87 % (Barcelona) and 89 % (Guayaquil) of respondents identified at least one pollutant among those listed in the survey (variable A-5; Table 1). In Barcelona, the most selected pollutant was particulate matter, followed by sulfur dioxide. This selection may be influenced by the presence of large mountains of petroleum coke that could be observed from outside the industrial

Table 5
Relationships between perception of pollution and health status-self-reported - Venezuela case.

Identificatory	Variable	7	8	9
1	A1. (Table 1) Events generated by air pollution	0.378**	0.274**	0.276**
2	A2. (Table 1)[a] Identify emission sources	0.299**	0.213**	0.254**
3	A3. (Table 1) Personal actions to improve air quality	0.145**	0.098	0.080
4	A4. (Table 1) Identify air pollution diseases	0.297**	0.298**	0.334**
5	A5. (Table 1) Identify air pollutants	0.193**	0.177**	0.322**
6	A2.7 (Table 1) Air is not polluted	−0.373**	−0.126*	−0.147**
7	D1. (Table 4) Do you consider air pollution a risk factor for your health?	1	0.461**	0.313**
8	D2. (Table 4) How do you rate your respiratory health?		1	0.269**
9	D3. (Table 4) Self-declared diseases			1

Note (*) $p < 0.05$. (**) $p < 0.01$.
[a] Without "air is not polluted" responses.

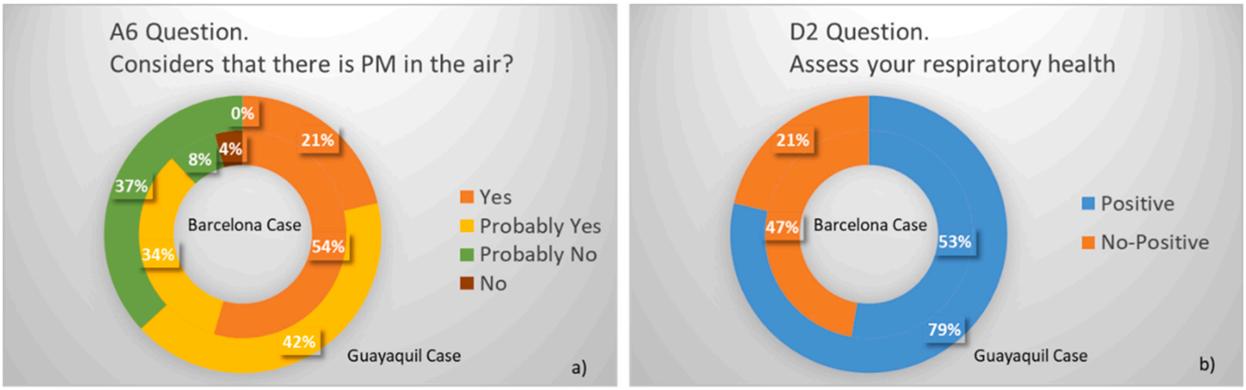

Fig. 3. Pollution perception (a); self-reported health (b); case studies Barcelona and surrounding cities and Guayaquil.

complex, resulting from a conveyor belt malfunction between 2012 and 2020 [47]. Sulfur dioxide is associated with emissions from the oil industry [6]. In Guayaquil, the two most frequently selected pollutants were carbon monoxide and particulate matter, which are related to vehicular emissions [40].

As for the diseases (variable A-3; Table 1), 96 % of the respondents selected at least one option in Guayaquil, and 91 % in Barcelona

Table 6
Assessment of air quality strengthening in Barcelona and surrounding cities, and Guayaquil.

Sector	Action	Venezuela	Ecuador
Industrial activities	1. Establishing incentives that promote investments in renewable energy, pollution control technologies, energy efficiency and clean production mechanism	(yellow)	(green)
	2. Increasing industrial energy efficiency	(grey)	(grey)
Road transport	3. Reduce sulfur content in diesel and petrol	(red)	(red)
	4. Tightening vehicle emission standards to at least Euro 4/IV-equivalent	(red)	(red)
	5. Increasing investments in public and nonmotorized transport infrastructure and systems	(red)	(yellow)
Open waste burning	6. Reduce open burning of municipal waste through provision of legislation, monitoring, enforcement and municipal waste management systems.	(yellow)	(yellow)
Legislative efforts	7. Establishing and continuously tightening ambient air quality standards to meet WHO recommendations	(red)	(green)
	8. Establishing laws and regulations to support efforts to meet ambient air quality standards, and strengthen monitoring and enforcement	(red)	(red)

Green = progressing to best practice; red = action still required, yellow = on the road to best practices; grey = Information not found.

and surrounding cities. In both cities, cough was the most selected respiratory illness.

The questionnaire used in this study successfully identified the relationship between health and pollution perception. Other studies have found similar relationships, and their results suggest that respondents who perceive pollution-related health issues tend to declare a positive WtP to improve air quality [48–52].

A review of WtP literature from 2010 onwards reveals global CVM studies assessing WtP for air quality improvements. A focus on the last 5 years, comparing methodologies in questionnaire design, data sources, limitations, and policy impact is available in the **Supplemental Information** S2. Key observations: (i) Most studies lack detailed CVQ presentation, with only one providing comprehensive details. (ii) Unlike studies in areas with established air pollution data, ours explores regions where it is less monitored. (iii) Similar to others, our study acknowledges CVM limitations and operational challenges. (iv) A shared goal among studies, including ours, is influencing local or national air pollution policy, aligning with government trends of funding CVM research for policy support [53].

In our study, the responses confirm that the respondents perceive the characteristics of air pollution in their area accurately, indicating that the instrument designed measures the variables of interest in a valid and differentiated way for each case study. Overall, the results of this study contribute to the understanding of the relationship between health and pollution perception and highlight the importance of considering contextual factors when interpreting self-reported health status.

4. Challenges for strengthening air quality

After confirming that Barcelona (surrounding cities) and Guayaquil are polluted cities, a qualitative analysis was performed to assess progress in strengthening air quality in these cities using the proposed activities from UNEPPAQ [16]. Table 6 displays eight actions categorized in four sectors suggested by UNEPPAQ for outdoor air. The last two columns show the outcomes of the qualitative evaluation.

4.1. UNEPPAQ sector: industrial activities

- Action 1: Establishing incentives for clean energy

We focused our analysis of the first action on the topic of incentives for renewable energy, due to the lack of information on the other topics considered in this action. In Venezuela, hydroelectric and thermoelectric power have been the primary sources of energy since 1946 [34,54]. Hydroelectric power generation reached its peak in 1994, accounting for 74.4 % of the national electricity supply, but decreased to 59.5 % in 2015 [34]. Major investments were made to the energy system between 2005 and 2015, but due to the collapse of oil revenues and the need for external financing, there have been few investments since then, resulting in a deteriorating electric system. This has led to frequent and prolonged power outages, which have had a negative impact on society [34,55]. The electric system in Barcelona is mainly powered by thermoelectric plants located in the study area, although it also receives electricity from the national hydroelectric system [34].

In 2020, Ecuador achieved a net energy production of 34,000 GWh, with hydropower accounting for 73.7 %, non-renewable sources accounting for 34.6 %, and unconventional sources accounting for 1.7 %. The government has incentivized investment in renewable energy, specifically in wind and solar energy, resulting in a projected significant shift toward renewable sources in the energy matrix in the coming years [56]. The legal and regulatory framework in Ecuador supports the growth of renewable energy, and the government's programs and plans for national development provide further opportunities for renewable energy investment. The government's annual budgets are driving diversification in renewable energy sources [56]. The electricity system in Guayaquil is partly powered by national hydroelectric sources and three local thermoelectric plants [38].

A qualitative analysis could not be performed for both Barcelona and Guayaquil for action 2, which focuses on increasing industrial energy efficiency, nor on the aspects of energy efficiency and clean production mechanisms of action 1, because insufficient information was available about this topic in both cities. This resulted in this action being classified as "grey" in the qualitative matrix.

4.2. UNEPPAQ sector: road transport

- Action 3: Reduce sulfur content in diesel and petrol/gasoline.

The maximum sulfur content allowed in gasoline in Venezuela is 600 ppm [57], while Ecuador permits 650 ppm for gasoline with 85 and 92 octane ratings and 300 ppm for gasoline with 93 octane rating [58]. For diesel, the maximum sulfur content is 300, 500, and 700 ppm, depending on the type of diesel [59]. These values exceed the fuel specifications for sulfur content of 10 ppm, established by the European Union and the United States Environmental Protection Agency [60,61]. Reducing the sulfur content in fuels primarily decreases SOx emissions. Additionally, it affects $PM_{2.5}$ emissions, as secondary $PM_{2.5}$ is generated in the atmosphere through the photochemical reaction of SO_2 [8,62].

- Action 4: Tighten vehicle emission standards to at least Euro 4/IV

In Venezuela and Ecuador, the regulations controlling mobile source emissions allow for the circulation of vehicles emitting at Euro I levels [63,64]. However, in Ecuador, vehicles manufactured after the year 2000 must comply with Euro IV standards, and Official

Ordinance 909 of 2013 mandates the annual vehicle inspection in Guayaquil, which has facilitated the mechanical maintenance of vehicles [38]. To implement vehicle emission standards, equivalent to EURO IV/4, it is necessary to reduce the sulfur content of fuels below 50 ppm [65].

- Action 5: Enhance funding and development of infrastructure and systems for public and nonmotorized transportation

Information on investment in public transport in Guayaquil is scarce. In 2022, Guayaquil put into operation an aerial cable car trunk line that connects it with a satellite city. Furthermore, the city introduced a municipal ordinance that offers financing incentives to private transportation cooperatives to acquire electric vehicles [38]. The last significant government investment in public transport was the Bus Rapid Transit System in 2002. As for Barcelona, there is no knowledge of any government investments in public transport. Neither city has taken any actions to promote the use of nonmotorized transportation.

4.3. UNEPPAQ sector: open waste burning

- Action 6: Reducing open waste burning

Venezuela generates around 0.88 kg of solid waste per person per day, with a municipal waste rate of 1.03 kg per inhabitant per day [66,67]. Only 10-15 % of the waste is recycled, and just 20 % undergoes appropriate final disposal [35]. These poor final disposal rates are due, in part, to the deficient national program for integrated solid waste management, which leads to an inefficient waste collection system [66,68].

Nationwide, 17.6 % of the Venezuelan population resorts to open waste burning, reflecting the severity of the waste management problem. In Barcelona, only 58.3 % of the service grid is covered by the urban solid waste collection services [69]. There is a law in Venezuela for integrated waste management which explicitly prohibits open waste burning [70].

In 2014, Ecuador generated 4.96 million tons of solid waste, with a municipal waste generation rate of 0.686 kg per inhabitant per day [42]. Other work reported a solid waste generation rate of 0.88 kg per person per day [67]. Waste collection in most of Ecuador's provinces is carried out without sorting, and only 20 % of the waste is adequately disposed of, with the rest being distributed among open dumps, controlled dumps, rivers, and incinerators. In Guayaquil, municipal waste is collected door-to-door without sorting and is then sent to landfills [41,42]. Ecuador also has regulations for integrated waste management [71]. Although there is insufficient official information on open waste burning in Guayaquil, there are newspaper articles and reports from the city's Fire Department warning the public not to burn waste and highlighting the fines imposed for doing so.

4.4. UNEPPAQ sector: legislative efforts

- Actions 7 and 8: strengthening ambient air quality standards and regulations.

Venezuela's air quality regulations are outdated and permissive, dating back to the mid-1990s. The following regulations, decrees, and laws were last updated in these dates: [63,72–76]. In 2016, Venezuela passed a national air law as a political effort, but none of the decrees were reviewed.

Although Venezuelan air quality regulations set standards for criteria pollutants, their thresholds are above the 2005 and 2022 WHO recommendations. Until 2012, Venezuela had a monitoring system that published information on annual TSP levels for some cities, including Barcelona [33]. However, this information is not yet up to date for 2022.

In 2015, the Ecuadorian environmental authorities approved the latest update to the environmental regulations [77], which adjusted the emission and air quality thresholds for criteria pollutants. The update aimed to meet the stricter interim targets proposed by the WHO Air Quality Guidelines by adjusting some thresholds. Specifically, the authorities lowered the PM_{10}-24 h threshold from 150 to 100 $\mu g\ m^{-3}$ and the $PM_{2.5}$-24 h threshold from 65 to 50 $\mu g\ m^{-3}$ to meet Interim Target 2 [4]. They also reduced the SO_2-24 h threshold from 350 to 125 $\mu g\ m^{-3}$ to meet Interim Target 1 [4].

The responsibility of ensuring the air quality of communities lies with local governments in Ecuador. However, it is unknown whether the local government of Guayaquil monitors the city's air quality. Even if they do, the information is not publicly available.

4.5. Qualitative discussion on the challenges for strengthening air quality

The positive willingness to pay for improving air quality in Barcelona and Guayaquil indicates that the population perceives these cities to be polluted. This perception is supported by studies on air quality and emission inventories that question the air quality of these cities [6–8,30]. To determine the actual degree of pollution in these cities, it is necessary to have continuous monitoring records that allow for the establishment of annual concentrations, at least for PM_{10} and $PM_{2.5}$. When consulting information, such as global maps of $PM_{2.5}$ based on local low-cost sensors, available monitoring data, and modeling, some information can be extracted, with uncertainty, for these cities (or countries). While these alternatives provide a general overview, they lack the resolution required for detailed research.

An analysis of Table 6 reveals that Venezuela's efforts to strengthen national air quality are insufficient. The country needs to strengthen its air quality and industrial and vehicular emissions regulations and ensure their compliance. It is also essential to reduce the sulfur content in fuels, increase investments in infrastructure and public transport systems, and monitor compliance with waste management regulations. It is also necessary to revive the environmental monitoring system that was active until 2012.

Of the seven analyzed actions, Ecuador has the best practices in two (renewable energy investments and strict air quality regulations). However, it needs to make efforts to reduce the sulfur content in fuels, which will also allow for the implementation of the Euro IV/4 regulations. Local government efforts should focus on increasing investments in infrastructure and non-motorized public transport systems, implementing an air quality monitoring system in Guayaquil, and increasing surveillance of open burning of waste.

5. Limitations and caveats

Section 4's assessment of air quality challenges relies on information availability, depth, and quality. We used a purpose-designed tool to evaluate the quality of references cited in Section 4 (excluding regulations). The tool assigned weights (0, 1, or 2) to seven criteria in a Likert-style assessment, with higher scores indicating higher quality. Scores were crucial for gauging the quality of reference information (see Supplemental Information S1 for details).

Quality assessment scores for 15 records ranged from 7/14 to 14/14. Four records achieved over 90 % marks, indicating high-quality studies. Approximately half of the studies (seven out of 15 records) demonstrated good quality, with assessment scores exceeding 75 %. However, two studies received low quality assessment scores of 7/14. The varied quality profile of the assessed records emphasizes the importance of exercising critical judgment and caution when interpreting the qualitative quality of the consulted records.

Uncertainties persist in our analysis. We lack vehicle inspection records and face uncertainties about vehicle registration, inventory, and essential details like ages, maintenance status, compliance with Euro 4 standards, and the prevalence of electric vehicles. The uncertainty extends to electricity supply details. Additionally, air quality information is scarce, real-time monitoring access is unavailable, and we harbor doubts about non-peer-reviewed web monitoring systems. It should be noted that official public information on energy supply, transport and air quality is scarce, so we are limited to good studies made by other researchers who have delved into these topics. In navigating these challenges, we've endeavored to make the best use of the available data.

The study encountered challenges from inadequate spatial and temporal $PM_{2.5}$ monitoring data in the two cities, restricting the depth of the analysis. There are inherent limitations associated with the CVM, that are associated with biases from applying questionnaire-type of instruments. The study is susceptible to the potential impact of sample type, question design and contextual factors on respondent perceptions and $PM_{2.5}$ estimates.

6. Conclusion

The questionnaire developed to assess the perception of air pollution and self-reported health has been shown to be reliable, valid, and reproducible, with an acceptable level of internal consistency. The results indicate a close relationship between the perception of air quality, self-reported health status, and willingness to pay. Specifically, perceiving higher levels of pollution is associated with reporting worse health outcomes, and vice versa. The questionnaire is a reliable tool to assess air quality based on citizens' perceptions, and the findings reveal that both populations perceive a low air quality in their respective cities. They also identify the emission sources and air pollutants accurately.

An analysis of the proposed activities by the United Nations Environment Programme for the Promotion of Air Quality highlights the challenges that still need to be addressed to strengthen air quality in Barcelona, surrounding cities, and Guayaquil. In Barcelona, it is necessary to act promptly, both at the local (urban transport, waste incineration) and national level (updating environmental and vehicle emission regulations, investing in renewable energies). In contrast, Guayaquil has already taken some measures to improve air quality, but further investments are needed in public transport and incentives for non-motorized transportation. The reduction of sulfur content in fossil fuels should be led by the national government in both countries. Unfortunately, there was insufficient information available to evaluate energy efficiency and clean production mechanisms currently held in place in both cities at the industrial level.

The survey and qualitative analysis support the need for local governments to take appropriate actions to address air quality challenges in line with the United Nations recommendations. For respondents in Barcelona, controlling industrial emissions should be a priority, while respondents in Guayaquil advocate reducing emissions from transport as crucial.

Data availability statement

Q. Has data associated with your study been deposited into a publicly available repository?
A. No.
Q. Please select why.
A. Data will be made available on request.

CRediT authorship contribution statement

Giobertti Morantes: Writing – original draft, Project administration, Methodology, Data curation, Conceptualization. **Gladys Rincon:** Writing – original draft, Methodology, Data curation, Conceptualization. **Alejandro Chanaba:** Writing – review & editing. **Benjamin Jones:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29211.

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