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Article

Quantifying the Impact of High Emitters on Vehicle CO Emissions An Analysis of Ecuador's Inspection and Maintenance Program

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Simple Summary: A concise summary of the paper's findings on high emitters and I/M programs.

Abstract: Vehicular emissions are a primary contributor to urban air pollution, and inspection and maintenance (I/M) programs are key strategies to mitigate this impact. However, the effectiveness of these programs can be limited by "high emitters"—vehicles that fail emission standards but continue to circulate until their next inspection. This study quantifies and compares vehicular CO emissions in Quito, Ecuador, under two distinct scenarios using the VEIN (Vehicular Emissions Inventory) model. The first scenario assumes all vehicles comply with average emission factors, representing a baseline without explicit consideration of high emitters. The second scenario explicitly accounts for the significant contribution of high emitters that pass the annual inspection and remain in circulation. Our findings highlight the substantial difference in total emissions between these scenarios, emphasizing the critical role of undetected high emitters in inflating overall pollution levels. This understanding can inform the design of more effective I/M programs and enhance air quality management strategies in Quito and other similar urban environments.

Keywords: Vehicular Emissions; Inspection and Maintenance (I/M) Program; High Emitters; VEIN Model; Air Quality; Ecuador; CO Emissions; Emission Inventory.

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1. Introduction

ntroduction: * Background: Discuss the significance of vehicular emissions in urban air quality, focusing on pollutants like CO. Mention the context of Quito, Ecuador, as a developing city with specific air quality challenges. * Problem Statement: Explain that while I/M programs are designed to reduce emissions, their effectiveness can be compromised by vehicles that fail emission tests but remain in use until the next inspection. These "high emitters" can disproportionately contribute to overall pollution. * Literature Review: * Discuss existing literature on vehicular emission inventories and modeling, highlighting the role of the VEIN model (Ibarra-Espinosa et al., 2018). * Review studies on the effectiveness of I/M programs globally and in Latin America. * Cite research on the concept and impact of "high emitters" or "gross polluters." * Research Gap: Clearly articulate that a detailed quantification of the impact of high emitters on total emissions, specifically within the context of Quito's I/M program, is lacking. * Objectives: * To estimate CO emissions from the gasoline vehicle fleet in Quito using the VEIN model. * To quantify the difference in emissions between a scenario that assumes uniform emission factors (without explicit high emitters) and a scenario that accounts for high emitters that pass the annual inspection. * To assess the potential impact of improving the detection and removal of high emitters

within Quito's I/M program. * Structure of the Paper: Briefly outline the sections of the manuscript.

2. Materials and Methods:

- Study Area: Describe Quito, Ecuador, including its geographical characteristics, typical traffic patterns, and existing I/M program details (e.g., frequency of inspection, detection methods).
- Information about Ecuador's I/M program can be found in sources like SGS Ecuador and general government regulations.
- VEIN Model Description:
- Explain the VEIN R package and its suitability for creating high-resolution, street-level emission inventories.
- Detail the specific functions used from VEIN, particularly ef_whe (emission factor with high emitters) if applicable, or how you adapted the model to incorporate your high-emitter calculation.
- Mention the input data required by VEIN (e.g., vehicle fleet composition, age, fuel type, pollutant, emission type, subtype).
- Data Sources:
- Vehicle Fleet Data: Specify how you obtained data on vehicle types (e.g., gasoline cars), their distribution, age, and size in Quito.
- Emission Factors:
- Scenario 1 (Without High Emitters): Describe the average emission factors used for compliant vehicles (e.g., 0.1 g CO/km as in your example). Specify the source of these factors (e.g., standard emission databases, local studies).
- Scenario 2 (With High Emitters):
- Explain how you defined "high emitters" – e.g., a multiplier of the average emission factor (e.g., 1 g CO/km in your example).
- Detail how you determined the proportion of "approving" (normal emitters) and "reproving" (high emitters) vehicles based on the annual inspection data (e.g., 80% approval, 20% reproval).
- Explain how these proportions and factors are used to calculate the weighted emission factors (as per your example: 0.80 * 0.1 g/km + 0.20 * 1 g/km = 0.28 g/km).
- Activity Data: Describe how you obtained or estimated vehicle activity (e.g., kilometers driven per year, per vehicle type). This is crucial for converting emission factors to total emissions.
- Pollutants and Emission Types: Specify which pollutants (CO, as per your example) and emission types (e.g., exhaust) are included in the analysis.
- Methodology for High Emitter Calculation:
- Provide a detailed explanation of your approach to calculating weighted emission factors, using the provided example as a basis.
- Explain how these weighted factors are applied within the VEIN framework.
- Describe how you simulate the "circulation until measurement" aspect – i.e., that reproving vehicles continue to emit at their higher rates until their annual inspection.
- Data Analysis and Modeling:
- Describe how you integrated the calculated emission factors and activity data into VEIN to produce emission inventories for both scenarios.
- Specify the temporal and spatial resolution of your inventory (e.g., hourly, street-level).
- Comparison Metrics: Define how you will compare the two scenarios (e.g., total CO emissions, difference in emissions as a percentage, contribution of high emitters to total emissions).

3. Results:

- Vehicle Fleet Characterization: Present a summary of the vehicle fleet used in the analysis for Quito (e.g., breakdown by age, type, fuel).

- Emission Factors: Show the calculated weighted emission factors for both scenarios (average vs. high-emitter accounted).
- Total CO Emissions:
- Present the estimated total CO emissions for Quito under Scenario 1 (without explicit high emitters).
- Present the estimated total CO emissions for Quito under Scenario 2 (with explicit high emitters).
- Clearly show the difference between the two scenarios.
- Contribution of High Emitters: Quantify the percentage contribution of the "reproving" (high emitter) vehicles to the total emissions in Scenario 2.
- Spatial/Temporal Distribution (Optional but Recommended): If VEIN allows, show how emissions differ spatially (e.g., hotspots) or temporally between the two scenarios.
- Statistical Significance (if applicable): If you perform any statistical tests to compare the scenarios.

4. Discussion:

- Interpretation of Findings:
- Discuss the magnitude of the difference in emissions between the two scenarios. Was it as expected?
- Explain why high emitters have such a significant impact, linking it to their higher emission rates.
- Relate your findings to the effectiveness of Quito's current I/M program. Does the annual inspection adequately capture and remove high emitters?
- Implications for I/M Programs:
- Discuss how the findings inform policy decisions related to I/M programs, such as the frequency of testing, the stringency of test limits, and the enforcement mechanisms.
- Consider the potential benefits of more frequent or more sensitive emission testing.
- Discuss the economic and environmental trade-offs.
- VEIN Model Application: Comment on the utility of the VEIN model for this type of analysis, particularly its ability to handle detailed emissions calculations.
- Limitations:
- Acknowledge any limitations in the data (e.g., accuracy of fleet data, activity data, emission factors).
- Discuss the assumptions made (e.g., constant emission rates for high emitters until inspection, homogeneity of vehicle population within categories).
- Mention any simplifications in the I/M program representation.
- Comparison with Previous Studies: Place your findings in the context of existing research on vehicular emissions and I/M programs.
- Future Research: Suggest areas for further investigation (e.g., including other pollutants, different vehicle types, other cities, the impact of different I/M strategies).

5. Conclusions:

- Summarize the main findings regarding the impact of high emitters on CO emissions in Quito.
- Reiterate the importance of effectively identifying and addressing high emitters in I/M programs.
- Provide a concise policy recommendation for improving air quality management in Quito based on your results.

This Rmd-skeleton uses the mdpi Latex template published 2023-03-25. However, the official template gets more frequently updated than the **rticles** package. Therefore, please make sure prior to paper submission, that you're using the most recent .cls, .tex and .bst files (available here).

Table 1. MDPI article types.

abstract	entry	retraction
addendum	expressionofconcern	review
article	extendedabstract	perspective
book	datadescriptor	protocol
bookreview	editorial	shortnote
briefreport	essay	studyprotocol
casereport	erratum	systematicreview
comment	hypothesis	supfile
commentary	interestingimage	technicalnote
communication	obituary	viewpoint
conferenceproceedings	opinion	guidelines
correction	projectreport	registeredreport
conferencereport	reply	tutorial

6. Article Header Information

The YAML header includes information needed mainly for formatting the front and back matter of the article. Required elements include:

```yaml
title: Title of the paper
author:
  - name: first and last name
    affil: |
      One or more comma seperated numbers corresponding to affilitation
      and one or more  comma seperated symbols corresponding
      optional notes.
    orcid: optional orcid number
affiliation:
  - num: 1,..., n for each affiliation
    address: required
    email: required
authorcitation: |
  Lastname, F.
correspondence: |
  email@email.com; Tel.: +XX-000-00-0000.
journal: notspecified
type: article
status: submit
```

Journal options are in Table 2. The `status` variable should generally not be changed by authors. The `type` variable describes the type of of submission and defaults to `article` but can be replaced with any of the ones in Table 1

6.1. Journal Specific YAML variables

```yaml
# for journal Diversity,
# add the Life Science Identifier using:
lsid: http://zoobank.org/urn:lsid:zoobank.org:act:nnnn


# for journal Applied Sciences
# add featured application
featuredapplication: |
```

```
  Authors are encouraged to provide a concise
  description of the specific application or
  a potential application of the work. This
  section is not mandatory.

# for the journal Data
# add dataset doi and license
dataset: https://doi.org/10.1000/182
datasetlicense: CC-BY-4.0

# for the journal Toxins
# add key contributions
keycontributions: |
  The breakthroughs or highlights of the manuscript.
  Authors can write one or two sentences to describe
  the most important part of the paper.

# for the journal Encyclopedia
encyclopediadef: |
  For entry manuscripts only: please provide a brief overview
  of the entry title instead of an abstract.
entrylink: The Link to this entry published on the encyclopedia platform.

# for the journal Advances in Respiratory Medicine
# add highlights
addhighlights: |
  This is an obligatory section in ‘‘Advances in Respiratory Medicine’’,
  whose goal is to increase the discoverability and readability of the
  article via search engines and other scholars. Highlights should not
  be a copy of the abstract, but a simple text allowing the reader to
  quickly and simplified find out what the article is about and what can
  be cited from it. Each of these parts should be devoted up to 2~bullet
  points.
```

Table 2. MDPI journal names.

atmosphere	coatings	engproc	hospitals	jsan	mti	powders	stresses
atoms	colloids	entomology	humanities	jtaer	muscles	preprints	surfaces
audiolres	colorants	entropy	humans	jvd	nanoenergyadv	proceedings	surgeries
automation	commodities	environments	hydrobiology	jzbg	nanomanufacturing	processes	suschem
axioms	compounds	environsciproc	hydrogen	kidneydial	nanomaterials	prosthesis	sustainability
bacteria	computation	epidemiologia	hydrology	kinasesphosphatases	ncrna	proteomes	symmetry
batteries	computers	epigenomes	hygiene	knowledge	ndt	psf	synbio
bdcc	condensedmatter	est	idr	land	network	psych	systems
behavsci	conservation	fermentation	ijerph	languages	neuroglia	psychiatryint	targets
beverages	constrmater	fibers	ijfs	laws	neurolint	psychoactives	taxonomy
biochem	cosmetics	fintech	ijgi	life	neurosci	publications	technologies
bioengineering	covid	fire	ijms	liquids	nitrogen	quantumrep	telecom
biologics	crops	fishes	ijns	literature	notspecified	quaternary	test
biology	cryptography	fluids	ijpb	livers	nri	qubs	textiles
biomass	crystals	foods	ijtm	logics	nursrep	radiation	thalassrep
biomechanics	csmf	forecasting	ijtpp	logistics	nutraceuticals	reactions	thermo
biomed	ctn	forensicsci	ime	lubricants	nutrients	receptors	tomography
biomedicines	curroncol	forests	immuno	lymphatics	obesities	recycling	tourismhosp
biomedinformatics	cyber	foundations	informatics	machines	oceans	regeneration	toxics
biomimetics	dairy	fractalfract	information	macromol	ohbm	religions	toxins
biomolecules	data	fuels	infrastructures	magnetism	onco	remotesensing	transplantology
biophysica	ddc	future	inorganics	magnetochemistry	oncopathology	reports	transportation
biosensors	dentistry	futureinternet	insects	make	optics	reprodmed	traumacare
biotech	dermato	futurepharmacol	instruments	marinedrugs	oral	resources	traumas
birds	dermatopathology	futurephys	inventions	materials	organics	rheumato	tropicalmed
bloods	designs	futuretransp	iot	materproc	organoids	risks	universe
blsf	devices	galaxies	j	mathematics	osteology	robotics	urbansci
brainsci	diabetology	games	jal	mca	oxygen	ruminants	uro
breath	diagnostics	gases	jcdd	measurements	parasites	safety	vaccines
buildings	dietetics	gastroent	jcm	medicina	parasitologia	sci	vehicles
businesses	digital	gastrointestdisord	jcp	medicines	particles	scipharm	venereology

cancers	disabilities	gels	jcs	medsci	pathogens	sclerosis	vetsci
carbon	diseases	genealogy	jcto	membranes	pathophysiology	seeds	vibration
cardiogenetics	diversity	genes	jdb	merits	pediatrrep	sensors	virtualworlds
catalysts	dna	geographies	jeta	metabolites	pharmaceuticals	separations	viruses
cells	drones	geohazards	jfb	metals	pharmaceutics	sexes	vision
ceramics	dynamics	geomatics	jfmk	meteorology	pharmacoepidemiology	signals	waste
challenges	earth	geosciences	jimaging	methane	pharmacy	sinusitis	water
chemengineering	ebj	geotechnics	jintelligence	metrology	philosophies	skins	wem
chemistry	ecologies	geriatrics	jlpea	micro	photochem	smartcities	wevj
chemosensors	econometrics	grasses	jmmp	microarrays	photonics	sna	wind
chemproc	economies	gucdd	jmp	microbiolres	phycology	societies	women
children	education	hazardousmatters	jmse	micromachines	physchem	socsci	world
chips	ejihpe	healthcare	jne	microorganisms	physics	software	youth
cimb	electricity	hearts	jnt	microplastics	physiologia	soilsystems	zoonoticdis
civileng	electrochem	hemato	jof	minerals	plants	solar	
cleantechnol	electronicmat	hematolrep	joitmc	mining	plasma	solids	
climate	electronics	heritage	jor	modelling	platforms	spectroscj	
clinpract	encyclopedia	higheredu	journalmedia	molbank	pollutants	sports	
clockssleep	endocrines	highthroughput	jox	molecules	polymers	standards	
cmd	energies	histories	jpm	mps	polysaccharides	stats	
coasts	eng	horticulturae	jrfm	msf	poultry	std	

7. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. Citing a journal paper [1,2]. And now citing a book reference Gujer [3]. Some MDPI journals use Chicago and others use APA, this template should choose the correct citation format for you once you specify the journal in the YAML header.

To use endnotes, change `endnotes: true` in the YAML header, then use `\endnote{This is an endnote.}`.

8. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

9. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

9.1. Subsection Heading Here

Subsection text here.

9.1.1. Subsubsection Heading Here

Bulleted lists look like this:

- First bullet
- Second bullet
- Third bullet

Numbered lists can be added as follows:

1. First item
2. Second item
3. Third item

The text continues here.

9.2. Figures, Tables and Schemes

All figures and tables should be cited in the main text as Figure **??**, 3, etc. To get cross-reference to figure generated by R chunks include the `\\label{}` tag in the `fig.cap` attribute of the R chunk:

When making tables using `kable`, it is suggested to use the `format="latex"` and `tabl.envir="table"` arguments to ensure table numbering and compatibility with the mdpi document class.

Table 3. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

	mpg	cyl	disp
Mazda RX4	21.0	6	160
Mazda RX4 Wag	21.0	6	160
Datsun 710	22.8	4	108
Hornet 4 Drive	21.4	6	258
Hornet Sportabout	18.7	8	360

For a very wide table, landscape layouts are allowed.

Table 4. This is a very wide table

Title.1	Title.2	Title.3	Title.4
Entry 1	Data	Data	This cell has some longer content that runs over two lines
Entry 2	Data	Data	Data

9.3. Formatting of Mathematical Components

This is an example of an equation:

$$a = 1.$$

If you want numbered equations use Latex and wrap in the equation environment:

$$a = 1, \tag{1}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{2}$$

Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

Example of a theorem:

Theorem 1. *Example text of a theorem*

The text continues here. Proofs must be formatted as follows:

Example of a proof:

Proof of Theorem1. Text of the proof. Note that the phrase "of Theorem 1'' is optional if it is clear which theorem is being referred to.

□

The text continues here.

10. Discussion

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

11. Conclusion

This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

12. Patents

This section is not mandatory, but may be added if there are patents resulting from the

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Conflicts of Interest: The authors declare no conflict of interest.

References

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