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Comparative analysis of COPERT and IVE models in road transport emission assessment

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ABSTRACT

Air pollution remains one of the most pressing environmental challenges worldwide, with road transport identified as one of the primary contributors to harmful emissions. Within the European Union, road transport accounts for 40.3% of total NOx emissions and 16.5% of PM2.5 emissions, demonstrating its significant impact on air quality. Accurate modeling of vehicular emissions is a fundamental step toward effective air quality management, identifying pollution sources, and formulating targeted mitigation strategies. This study conducts a detailed comparative analysis of two widely used emission models, COPERT and IVE, focusing on their performance under varying regional contexts, levels of data availability, and specific emission-related tasks. Key aspects such as model accuracy, usability, input data sensitivity, and policy assessment applicability are critically evaluated. The rationale for selecting these two models lies in their extensive application in European and non-European regions, offering a unique perspective on their adaptability and limitations in diverse scenarios. By identifying the strengths and weaknesses of COPERT and IVE, this work provides practical guidance for their optimal use in emission inventories, policy evaluations, and reduction strategy designs. The findings aim to bridge the gap between theoretical modeling approaches and real-world applications, equipping environmental managers and policymakers with actionable insights to enhance air pollution control measures and protect public health.

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1. Introduction

Air pollution is recognized as one of the greatest environmental challenges globally, with undeniable impacts on human health, climate change, and quality of life (Li et al., 2022). Road transport is highly polluting, especially in urban areas, and it constitutes the main source of greenhouse gases and damaging pollutants such as NOx, CO, NMVOCs, PM_{10}, and $PM_{2.5}$ (Puliafito and Allende, 2017). According to the report of EEA, road transport accounts for 40.3% of NOx emissions and 16.5% of $PM_{2.5}$ emissions in all 27 EU countries. Therefore, this sector requires more precise and optimized control of pollutant emissions. Emission modeling is one of the major tools in air quality management-related studies, which involves the assessment of pollutant levels from various transport sources and the development of effective reduction strategies. A number of models have been developed for estimating emissions of pollutants from mobile sources, each with its own features, applications, and limitations. These models simulate the road and realistic conditions of the vehicle, as well as the impact of factors such as fuel type and emission norms, driving conditions, and maintenance status, to provide more accurate emission estimates (Xu et al., 2023). The most widely used and renowned emission models are the COPERT (the Road Transport Emission

Calculation Model) and the IVE, or International Vehicle Emission Model. COPERT, originally developed for European countries, estimates these emissions with a great degree of accuracy and has prognostic capabilities with different driving conditions and Euro emission standards (Ali et al., 2021). On the other hand, the IVE model, designed for international vehicle emission assessments, has distinct features that make it suitable for broader, global analyses (Gao et al., 2022). The COPERT model, as one of the widely-used tools in this field, has been utilized in several studies. For instance, **(**Kawsar et al., 2024) in Bangladesh demonstrated through COPERT 5.5 that this software is highly applicable for modeling CO_2 emissions and updating emission factors for different vehicle categories. The results of this study confirm that COPERT can serve as a valuable tool in developing countries. Other studies have focused on comparing different models. In this context, (Trejos et al., 2020) simulated pollutant emissions in the city of Manizales, Colombia, using COPERT 5.3 and the IVE model. They identified discrepancies in the emission estimates provided by the two models. These comparisons highlight the necessity of adapting models to local conditions and the specific characteristics of the vehicles in use.

The IVE model has also been employed in studies such as the research by (Chaudhry and Elumalai, 2024) in India. This study analyzed data related to students' transportation and found that implementing sustainable transport policies significantly reduced vehicle emissions. Additionally, (Alipourmohajer et al., 2019) in Iran assessed the IVE model for the SAIPA vehicle fleet. The findings revealed that the IVE model could accurately verify pollutant emissions by comparing them with laboratory data and Euro 4 standards. The primary aim of this paper is to introduce and examine the COPERT and IVE models as key tools in pollutant emission assessment. This paper compares the performance, applications, and limitations of these two models, analyzing their advantages and challenges. Additionally, the paper discusses how these models can be used under various driving conditions and emission standards. These analyses will help researchers, policymakers, and environmental managers choose the appropriate model for pollutant emission assessment and implement more effective air pollution reduction strategies.

2. Material and methods

2.1. IVE model

The International Vehicle Emissions (IVE) software is used to estimate fleet emissions and it is a computer program developed in the Java programming language and designed to estimate mobile source emissions (Patino-Aroc et al., 2022). This model predicts local air pollutant emissions, greenhouse gas emissions, and toxic pollutants. It was developed through a joint effort by the University of California, Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT). According to the Global Sustainable Systems Research (GSSR) and the International Sustainable Systems Research Center (ISSRC), the most important input in IVE is driving behavior (Ghaffarpasand et al., 2021). This software uses vehicle-specific power (VSP) and engine stress to obtain the mentioned correction coefficients (Yu et al., 2021). The VSP index depends on instantaneous speed, height change, vehicle weight, drag coefficient, and air density (Sanches et al., 2021). The emission estimation process in the model is the product of the baseline emission rate for each technology in each modification Correction factors are classified into several categories (Table 1) (Alipourmohajer et al., 2019).

Table 1. Parameters to calculate emissions in IVE model.

Local Variables	Fuel Quality Variables	Power & Driving Variables
Ambient Temperature Ambient Humidity Altitude Inspection/Maintenance Programs Base Emission Adjustment	Gasoline Overall Gasoline Sulfur Gasoline Lead Gasoline Benzene Gasoline Oxygenate Diesel Overall Diesel Sulfur	Vehicle Specific Power Road Grade Air Conditioning Usage Start Distribution

This model needs three input files including fleet data, vehicle activity (such as driving behavior) for the desired location, and basic settings, six types of data are needed to prepare the fleet file: Fleet title, fuel type (gasoline, diesel, propane, ethanol, CNG, LPG, and special fuels), fuel system (carburetor, single-point injection, multi-point injection, pre-injection, direct injection, 2-stroke and 4-stroke, type and the characteristics of the vehicle, the distribution percentage of the desired vehicle, the distribution of the use of the air conditioning system, based on this, a total of 1471 technologies are given in the model, of which 1372 are predefined and the rest can be defined by the user. In each technology, there are 6 features, including car size (7 modes), fuel type (5 modes), vehicle usage (3 modes), fuel system (3 modes), vapor control system (variable), and exhaust output control system. (Variable) and the exhaust output control system is (variable). In this model, Eqs. 1 and 2 are used for light and medium cars:

$$\mathrm{VSP}\left(\frac{\mathrm{kW}}{\mathrm{metric}} - \mathrm{ton}\right) \quad (1)$$
$$= v \times (a \times (1 + \varepsilon_i) + g \times \mathrm{grade} + g \times C_R) + \frac{1}{2} p_a \frac{C_D \times A}{m} (v + v_w)^2 v + C_{if} \times g \times C_R$$
$$= v \times [1.1a + 9.81 \times (a\tan(\sin(\mathrm{grade}))) + 0.132] + 0.000302 \times v^3$$

where:

$$v = \mathrm{speed}\left(\frac{m}{s}\right)$$
$$a = \mathrm{acceleration}\left(\frac{m}{s^2}\right)$$
$$m = \mathrm{vehicleweight(kg)}$$
$$\varepsilon_i = \mathrm{massfactore, equivalenttothemassoftherotatingparts\ (wheels, gears, shafts, etc.)\ atpowertrain(withoutunit).}$$
$$\mathrm{thesuffixiindicatesthat}\varepsilon_i\mathrm{dependsongear, tilt, elevation, andlandinglength.}$$
$$g = \mathrm{gravityacceleration}9.8\left(\frac{m}{s^2}\right)$$
$$C_R = \mathrm{Resistancecoefficient}(m^2)$$
$$p_a = \mathrm{Thedensityoftheoutsideairis}1.207\frac{kg}{m^2}\mathrm{at}20^{\circ}C$$
$$v_w = \mathrm{Oppositewinddirection}\left(\frac{m}{s}\right)$$

todeterminetheenginestress, Equation(2)isalsoemployed:

$$\mathrm{Enginstress} = \mathrm{RPMIndex} + \left(0.08\frac{\mathrm{ton}}{\mathrm{kW}}\right) \times \mathrm{Preaveragepower} \quad (2)$$
$$\mathrm{preaveragepower} = \mathrm{Average}(\mathrm{VAP}_{t=-5\,\mathrm{sec\,to}-25})\left(\frac{\mathrm{kW}}{\mathrm{ton}}\right)$$
$$\mathrm{RPMIndex} = \mathrm{Veloocity}_{t=0}/\mathrm{SpeedDivider(withoutunit)}$$
$$\mathrm{MinimumRPMIndex} = 0.9$$

After completing the location data in the IVE model, the concentration of CO, VOC, VOCevap, Sox, NOx, and PM, as well as toxic pollutants and gaseous factors affecting global warming can be estimated daily or hourly in both start-up and driving modes. This model requires three input files, including fleet data, location data, and a basic settings section. Preparing the fleet file involves specifying fuel type (gasoline, diesel, propane, ethanol, CNG, LPG, and specific fuels), fuel system (carburetor, single-point injection, multi-point injection, pre-injection, direct injection, 2-stroke, and 4-stroke), vehicle type and characteristics, percentage distribution of the target vehicle, and the distribution of air conditioning usage. Accordingly, a total of 1,471 technologies are included in the model, of which 1,372 are predefined, and the remainder can be defined by the user. Each technology includes six features: vehicle size (7 categories), fuel type (5 categories), vehicle application (3 categories), fuel system (3 categories), vapor control system (variable), and exhaust emission control system (variable). Fig. 1 shows the fleet page in the IVE software (Viteri et al., 2022).

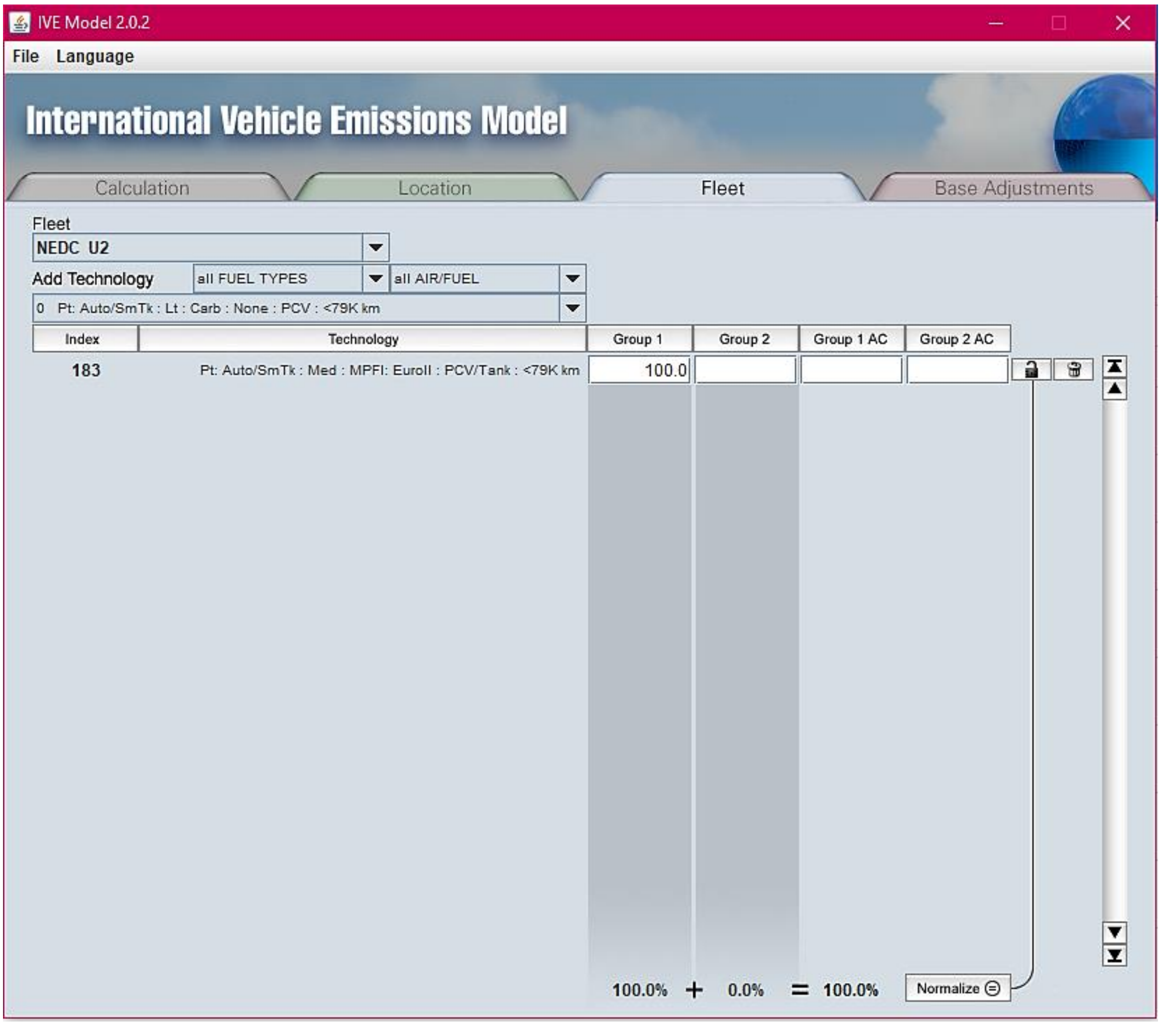

Fig. 1. Fleet profile page in IVE.

The location data section in IVE includes various information, such as environmental conditions (temperature, humidity, altitude), fuel characteristics (e.g., sulfur content percentage, benzene content, oxygenate compounds, etc.), and vehicle fleet composition in the study area. It also includes driving pattern information, such as the percentage of time spent in each mode, total distance traveled, and average speed. Additionally, data on vehicle startup percentages in each mode (number of starts and the elapsed time since startup) are included to calculate emissions from cold starts. The location data page in IVE software is shown in Fig. 2. The Base Adjustments section in the IVE model provides 45 undefined technologies that can be used to modify baseline emission factors and improve calculations using local emission measurements. Fig. 3 illustrates the Base Adjustments page in the IVE model (Saberiyansani et al., 2024).

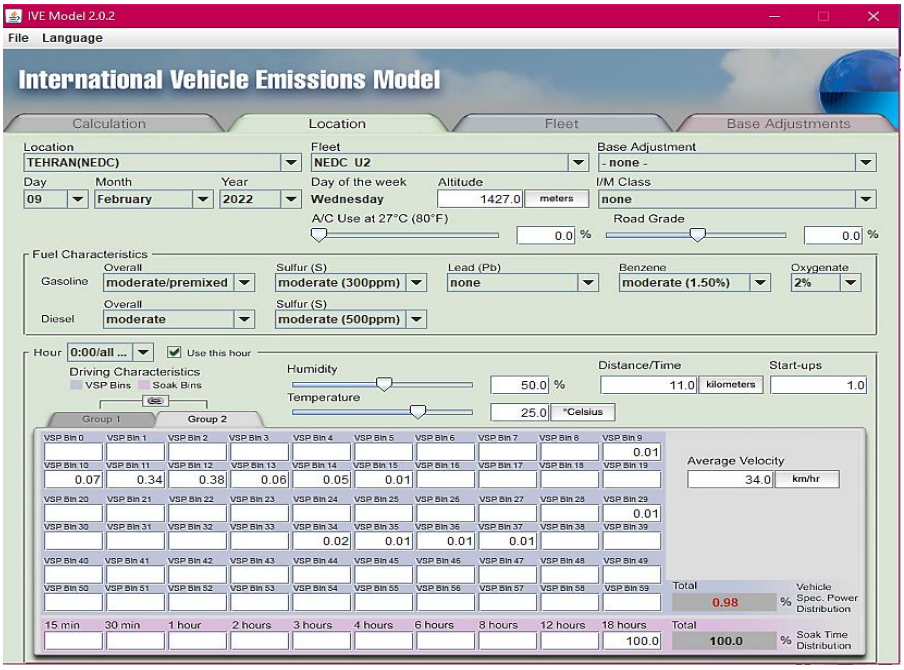

Fig. 2. Location data page in IVE software.

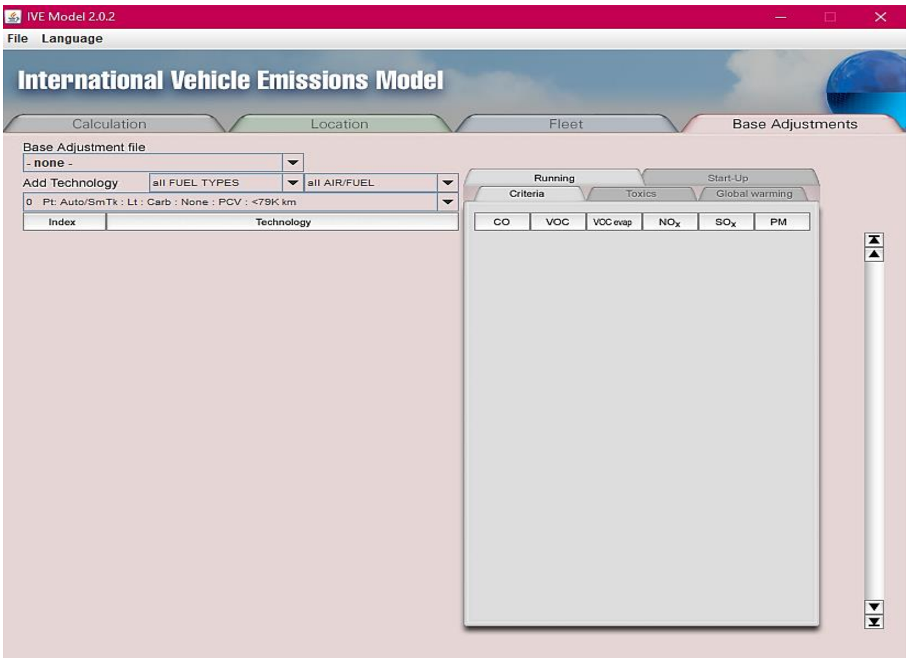

Fig. 3. Basic settings page in IVE model.

2.2. COPERT model

COPERT is a large-scale vehicle emission model developed by the European Environment Agency, which currently is the most diffused vehicle emission model in Europe (Piscitelli, Valenzano, et al. 2019). First published in 1989, the latest version, 5.6.1, was released more recently. The model was updated first in 1991 for the CORINAIR inventory. A second update was introduced in the COPERT II software tool, which added a wider classification of vehicles, more pollutants, and revised road and engine load profiles. The COPERT III model became very popular, and by 2003, it was used by about 15 European countries for their official emissions estimations. This model calculates the real-condition vehicle emission factor based on the original emission factor and the use of a column correction factor. The COPERT model can reflect the number of vehicle emissions in different countries and regions, calculate the correction factor according to the local information input by the user, and obtain the local emission list. The data of this model is mainly from bench test data collected by EU countries (Li, et al., 2019). In this model, based on the data collected from vehicles by road transport, a total inventory of vehicle classification will be analyzed. This inventory is primarily used to prepare the raw vehicle data to be used by the COPERT software. COPERT software usually calculates the emission rate of road transport vehicles by determining the emission coefficient for each category, engine technology, and engine capacity of vehicles. Thus, classification is done based on the requirements of COPERT software.

COPERT makes use of the number of vehicles, mileage, and speed, as well as a great deal of other information including the ambient temperature, for calculation. It calculates the amount of emission and energy consumption for any given country or region by considering all major pollutants, greenhouse gases, air pollutants, and toxic species. This is the average emissions and estimated model for the emissions of CO, NOx, HC, CH_4, CO_2, N_2O, NH_3, SOx, particulate matter, as well as estimates of heavy metals, polycyclic aromatic hydrocarbons, and persistent organic pollutants (Restrepo and Posada, 2018). Vehicle emissions in the COPERT III model are analyzed based on the three main conditions of driving, namely urban, rural, and highway. Each category is linked with a different pattern of driving that causes a different level of emissions. Emissions for each condition are calculated separately, while the total estimate of emissions is done by adding all of them together with the help of the Eq. 3:

$$E_{total} = E_{urban} + E_{rural} + E_{highway} \quad (3)$$

2.2.1. Key features of the COPERT model

2.2.1.1. Cold start and hot operation of the engine

The model accounts for emissions produced during the cold start phase (when the engine has not yet reached its optimal operating temperature) and hot operation (when the engine operates under ideal conditions). Cold starts generally result in higher emissions due to incomplete combustion.

2.2.1.2. Evaporative emissions

The COPERT III model also includes estimates of emissions caused by fuel evaporation, such as:
- Daily fuel vapor emissions.
- Emissions from fuel evaporation due to engine and vehicle heat.
- Losses from fuel storage and movement.

2.2.1.3. Total emissions estimation

The overall emissions are calculated by combining three main components (Eq. 4):

$$E_{total} = E_{hot} + E_{cold} + E_{evap} \quad (4)$$

2.2.1.4. Significance of the COPERT model in air pollution management

This model is a critical tool for policymakers and researchers, enabling them to analyze emissions under varying driving conditions and identify the contribution of each factor to total pollution. By providing detailed insights, it facilitates the development of effective strategies to reduce air pollution. In cities with heavy traffic and specific climatic conditions, such as Tehran, this model's application can significantly aid in decision-making to improve air quality and public health.

Let me know if you'd like more details about the inputs or calculations used in this model!
The COPERT software is divided into several key sections to comprehensively calculate and analyze emissions:
Vehicle Fleet Composition: This section allows users to define the characteristics of the vehicle fleet, including vehicle categories such as passenger cars, light-duty vehicles, and heavy-duty vehicles. It also incorporates details like fuel types (e.g., petrol, diesel, LPG, CNG) and emission control technologies (e.g., Euro standards).
Emission Calculations: COPERT calculates emissions for various pollutants, including greenhouse gases (CO_2, CH_4, N_2O), air pollutants (NOx, PM, VOCs), and toxic compounds. Emission factors are based on extensive data and account for variables like vehicle operation mode (hot engine, cold start, non-exhaust).
Driving Patterns: This module captures driving behaviors and usage conditions, such as average speed, road type distributions, and urban versus rural driving ratios.
Fuel Characteristics: Users can input fuel specifications, including sulfur content, benzene percentage, and oxygenate levels, to refine emission calculations.
Environmental Settings: COPERT incorporates environmental conditions like temperature, humidity, and altitude, which influence emissions.
Emission Outputs: The software generates detailed reports that can be used for national, regional, or local studies. Results are exportable in various formats to integrate with other tools like GAINS or TREMOVE for policy impact assessments.
COPERT is widely used for policy development, air quality modeling, and reporting emissions to entities like the UNFCCC and UNECE. It is regularly updated to include new vehicle categories, methodologies, and standards. Fig. 4 shows the COPERT software.

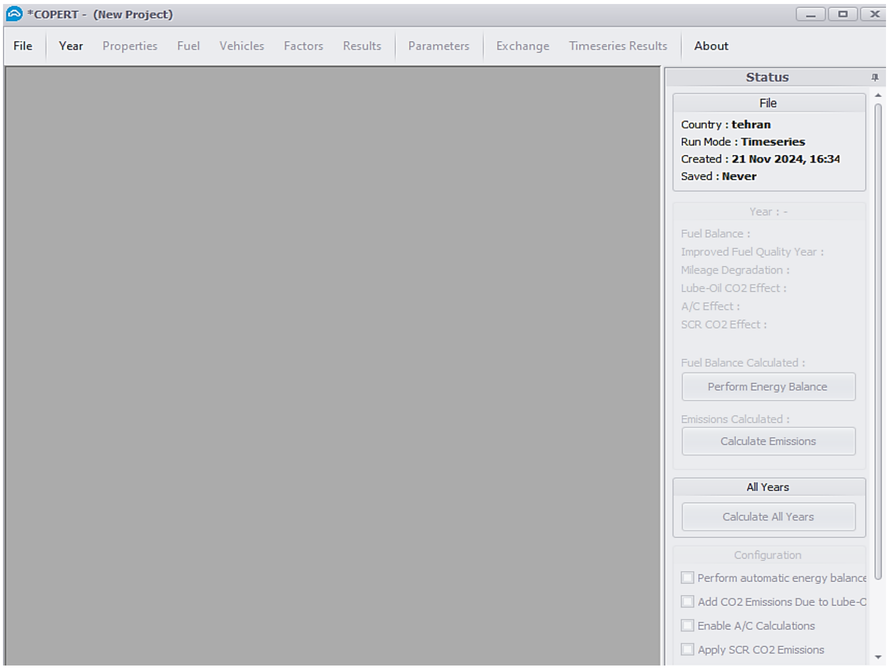

Fig. 4. The COPERT software.

3. Results and discussion

3.1. Comparison of COPERT and IVE Models in vehicle emission studies

Many vehicle emission studies used a plethora of models, which had the aim of achieving an understanding of applicability under differing conditions. Compared in the Table 2, for the ease of references, some recent research refers to information on study title, authors, models, geographic region, source of data, and findings of the research. It thereby provides broad contrast regarding differing models in light of bringing out strengths and weaknesses presented by each when performing a given assessment of emissions toward supporting choice of applicable tool for the future assessments.

Table 2. Summary of studies on vehicle emissions using COPERT and IVE models.

Title	Source	Model	Country/Region	Data Used	Results/Findings	Reference
Evaluation of COPERT 5.5 Software for Pollutant Emission in Bangladesh	Ahsanullah University	COPERT 5.5	Bangladesh	World Bank data, COPERT 5.5	COPERT 5.5 is applicable for modeling CO_2 emissions in Bangladesh, updating emission factors for different vehicle categories.	(Kawsar et al., 2024)
High-Resolution Vehicle Emission Inventory for Ecuador Using IVE Model	Polytechnic University of Madrid	IVE	Ecuador	Data from various provinces, driving patterns, vehicle features	Identified critical emission areas in Ecuador and the significant role of trucks in CO and other pollutants emissions.	(Viteri et al., 2023)
Vehicle Emission Inventory in an Andean City Using COPERT 5.3	AGU Annual Meeting Abstracts	COPERT 5.3	Colombia (Manizales)	Data on vehicles and pollutants from 2017	Simulated pollutant emissions using COPERT 5.3, comparing results with IVE, revealing differences in emissions estimates between the two models.	(Trejos et al., 2020)
Assessment of Sustainable School Transport Policies on Vehicular Emissions Using the IVE Model	Journal of Cleaner Production	IVE	India	Data from 945 students to determine transport preferences and school transport models	Significant reduction in vehicle emissions with the implementation of sustainable transport policies.	(Chaudhry and Elumalai 2024)
Two-Stream Networks for COPERT Correction Model with Time-Frequency Features Fusion	Atmosphere	Two-Stream Network	China	OBD data from heavy-duty diesel vehicles	Improved COPERT model accuracy by integrating time-series and time-frequency features through a two-stream network.	(Xu et al., 2023)
Evaluation of Urban Vehicle Emissions Using Traffic and Emission Models	Egyptian International Journal of Engineering Sciences and Technology	COPERT, VISSIM	Egypt (Zagazig)	Traffic simulation data from VISSIM	Simulated traffic and pollutant emissions using COPERT software, examining the impact of traffic on air pollution at three intersections.	(Gamal et al., 2024)
Verification of IVE Model for SAIPA Co. Fleet Emission	Pollution	IVE	Iran (Tehran)	Test data and laboratory results for SAIPA vehicles	Verified pollutant emissions from SAIPA vehicles using the IVE model, comparing them with Euro 4 standards and laboratory test results.	(Alipourmohajer et al., 2019)

3.2. Meta-Analysis of vehicle emission models comparison

3.2.1. Overview and objective

This meta-analysis compares studies using different vehicle emission models (COPERT and IVE) across various countries. The goal is to highlight trends, performance, and applicability of these models in different contexts, using a structured comparison framework (Table 3).

Table 3. Key criteria comparison: COPERT vs IVE Models.

Criterion	COPERT Studies	IVE Studies	Comparative Insights
Model Version	COPERT 5.5, 5.3	IVE	COPERT offers various versions; IVE remains consistent but may require updates.
Countries/Regions	Bangladesh, Colombia, China, Egypt	Ecuador, India, Iran	Global applicability tested in diverse regions. COPERT is used more widely across different regions.
Data Sources	World Bank, local traffic, OBD, VISSIM	Provincial data, school surveys, lab results	IVE often relies on detailed, localized real-world data, while COPERT uses aggregated and standardized datasets.
Key Findings	Effective for CO_2 and pollutant modeling, highlights emission factor updates	Useful for identifying critical emission sources and testing sustainable policies	COPERT emphasizes CO_2 emissions and standardization; IVE focuses on localized pollutants and policy impact.
Model Strengths	Accurate for general emission factors, integrates large-scale data	Suitable for detailed local inventories, adaptable for specific vehicle types	COPERT is more suitable for large-scale inventories; IVE excels in local, detailed assessments.
Challenges	Requires regional calibration, especially in developing countries	Limited applicability to broader contexts without data adaptation	Both models require regional data calibration for accuracy.

3.2.2. Model-Specific insight

3.2.2.1. COPERT-Based studies

Strengths: Effective for large-scale emission inventories, standard emission factors.
Limitations: Needs regional calibration; may not capture localized driving behavior accurately.
Example: In Bangladesh, COPERT 5.5 successfully modeled CO_2 emissions using World Bank data.

3.2.2.2. IVE-Based studies

Strengths: Detailed, local-scale emission estimates, adaptable for specific vehicle fleets.
Limitations: Limited to regions with detailed driving and vehicle data.
Example: In Ecuador, the IVE model identified key emission areas and pollutant contributors, particularly trucks.

COPERT is more suitable for broad, standardized emission assessments across various countries, while the IVE model is better for detailed, localized studies and specific policy evaluations. Integration or hybrid approaches could enhance accuracy and applicability in diverse regions.

3.2.3. Other emission models

Emission models are very important in estimating urban air pollution. However, regional differences in emission factors require local solutions in addition to the international models. Notable models include:

• **EMBEV**: This is the model changed and enhanced to be specified for Beijing, Macao, and Nanjing. In most areas of those regions, a characteristic that requires specific modeling expertise and capabilities in predicting pollutant emissions.
IVE-China: A regional model, specific for Chinese driving patterns, proper for detailed emission analysis in Chinese cities.
• **MOVES-Motor Vehicle Emission Simulator**: Elaborate model by U.S. EPA, in very wide application for vehicle detailed emission estimates within the U.S., provides sophisticated pollutant analyses using extensive simulations.
• **CALINE**: This is a model for the estimation of vehicular traffic pollutant dispersion, especially in urban areas, and is very useful for assessing air quality in highly trafficked areas.
• **EMFAC**: A model developed for California's vehicle fleet, providing high accuracy in emission inventories under strict environmental standards.
Limitations, such as models that are not open source or those that have static assumptions, have also been addressed by the development of innovative tools.
• **DVEM (Dynamic Vehicle Emission Model)**: This model can allow for stochastic predictions by the Monte Carlo simulation, taking into account variable numbers of vehicles, VKTs, and EFs. The model gives more accurate predictions of the pollutants.
• **VEIN**: An open-source R-package for bottom-up emission inventories, which integrates data from COPERT and U.S. EPA.

This model provides spatial-temporal distribution of emissions and is compatible with models like WRF-Chem.

Among those used, there are some quite popular models concerning GHG emissions:

1. **GREET**: A full life-cycle analysis model that gives in-depth information on vehicle technologies and fuels, with a specific focus on GHG emissions and pollutants throughout the vehicle lifecycle.
2. **LEAP**: Long-range Energy Alternatives Planning System is a model for the analysis of global energy and climate policy scenarios that evaluate the effect of energy and climate strategies.
3. **TREMOVE**: A European model dedicated to transport policy assessment, with a focus on emissions and economic impacts. It is quite helpful for transportation planning in Europe.
4. **The Intergovernmental Panel on Climate Change Emission Factor Database** is a database developed under the auspices of the Intergovernmental Panel on Climate Change and covers emissions factors for use at both the global climate change level and the national level.
5. **SODA** [Sustainable Development Goals & Emissions Modeling]: A new model, developed to assess the effect of sustainable development and reduction in emissions at both global and local levels.

The model choice depends on the needed scope and depth of the analysis, whether for detailed technology-specific analysis or broader policy evaluations. Ultimately, model choices will depend upon many variables, including geographic scale, types of pollutants, data available, and analytic objective (Zhong et al., 2024). As presented in Table 4, a comparison of the COPERT and IVE models for emission estimation is provided.

Table 4. Comparison of COPERT and IVE models for emission estimation.

Category	COPERT Model	IVE Model
History and Development	Introduced by the European Environment Agency (EEA) for emission assessment in European countries.	Developed by ISSRC, focusing on developing countries and local driving patterns.
Structure	Input: Vehicle type, speed, fuel; Output: CO, NOx, PM emissions.	Input: Local driving patterns, climate conditions, fleet characteristics; Output: Emission estimates.
Applications	Used for emission assessments in European countries, also linked to EU policy.	Applied in emission assessments in developing countries like Asia and Latin America.
Advantages and Limitations	High accuracy for standard conditions but requires updated and precise data.	Adaptable to local data but challenging in data collection and high complexity.
Geographic Scope	Primarily for Europe and countries with standard data.	Primarily for developing countries with specific local conditions.
Input Data	Requires fixed, standardized data.	Relies heavily on local, specific data.
Outputs	Provides comprehensive emission information, especially for CO_2.	Offers a broader scope of emissions but with less precision for CO_2.
Ease of Use	Easier to use with less technical expertise, but limited by standard conditions.	More flexible but more complex and requiring expertise.
Case Studies and Applications	Used extensively across Europe for emission inventories and policy evaluation.	Applied in countries like India, Iran, and others, with mixed results in emission predictions.
Challenges and Opportunities	Data access limitations, need for model adaptation in specific regions.	Data gathering challenges, potential for AI integration to simplify data collection.

References for the Table:

1. European Environment Agency - COPERT.
2. Joint Research Centre - COPERT.
3. International Energy Agency (ISSRC) - IVE Model.

4. Conclusions

Comparative Insights into Models Regulating Vehicle Emissions:

This meta-analysis presents the comparison of COPERT and IVE emission models in various studies and regions, highlighting their respective strengths, limitations, and applications based on contextual factors such as geographic scope, data availability, and research objectives.

COPERT Model:

• **Applications**: Widely applied in large-scale emission assessments, especially within European and standardized contexts.

• Advantages:

- High precision in overall CO_2 and common pollutant emission estimates.
- Suitable for macroscopic studies and policy evaluations.

• Challenges:

Requires regional calibration, especially for developing nations.

- Might not capture localized driving behaviors.

IVE Model:

• **Applications**: Useful for small-scale, detailed emission inventories, specifically for developing countries such as Iran, Ecuador, and India.

• **Advantages:**

- Flexible and adaptable to specific local condition and fleet characteristics.
- Effective to appraise the impacts of policies at the local level, for example, in the development of sustainable transport.

• **Challenges:**

- Relies heavily on detailed, region-specific data, which can be complex and costly to collect.
- Limited in generalizability to broader contexts without extensive data adaptation.

Key Findings:

• **COPERT-Based Studies:** Established efficiency in the modelling of CO_2 emissions as well as the standard pollutants. For instance, COPERT 5.5 did a satisfactory calculation of the country's CO_2 emission when applied in Bangladesh with raw data obtained from the World Bank; the model outcome emphasized that updated emission factors are critical.

• **IVE-Based Studies:** Illustrated the strong points of the model for source apportionment and policy impacts evaluation. In Ecuador, for example, the application of IVE was able to identify big contributors of pollutants, which turned out to be quite appropriate for small-scale and localized analysis.

Recommendations for Future Research:

• **Hybrid Approaches:** Hybrid models could take large-scale, standardized data from COPERT and add in real-world, local inputs from an IVE model.

• **Artificial Intelligence Integration:** Integrating AI into model calibration and even data gathering could raise the bar for predictions with reduced complexity.

• **Accounting for Real-World Data:** The inclusion of real driving habits and real traffic in the emissions model yields more realistic values and is useful, particularly when results are required in policy decisions.

This depends on the extent and scale of the study. While COPERT is ideal for broad standardized emission evaluations, IVE is preferred in detailed, localized evaluation studies. A hybrid that can combine these strengths will provide a robust tool for policymakers to develop effective environmental regulations and mitigation strategies.

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