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A Comprehensive Emissions Model Combining Autonomous Vehicles with Park and Ride and Electric Vehicle Transportation Policies

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Abstract: Several transport policies reduce pollution levels caused by private vehicles by introducing autonomous or electric vehicles and encouraging mode shift from private to public transport through park and ride (P&R) facilities. However, combining the policies of introducing autonomous vehicles with the implementation of electric vehicles and using the P&R system could amplify the decrease of transport sector emissions. The COPERT software has been used to calculate the emissions. This article aims to study these policies and determine which combinations can better reduce pollution. The result shows that each combination of autonomous vehicles reduces pollution to different degrees. In conclusion, the shift to more sustainable transport modes through autonomous electric vehicles and P&R systems reduces pollution in the urban environment to a higher percentage. In contrast, the combination of autonomous vehicles has lower emission reduction but is easier to implement with the currently available infrastructure.

Keywords: autonomous vehicles; park and ride; electric vehicle; transportation policies; emissions; transport emissions

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1. Introduction

A sustainable urban mobility plan (SUMP) is a plan that combines short-, medium-, and long-term policies and mobility strategies providing citizens with an environmentally friendly city [1]. Hence, a range of strategies based on the SUMP includes transport policies aimed to minimize emissions by private vehicles in the urban area. There are environmentally sustainable policies that include replacing traditional private vehicles with electric ones [2]. On the other hand, the modal interchange point within the urban environment between private vehicles and public transport consists in the establishment of a park and ride (P&R) system [3]. A recent approach is introducing autonomous vehicles in an urban environment [4–6]. The local government's transport policies in the SUMP can independently apply all these policies or strategies. However, it is worth examining the combination of policies to decide which one is the most suitable and effective in reducing emissions [7].

Transport policies or strategies concerning replacing a percentage of a city's vehicle fleet of private vehicles with conventional technology by private vehicles with electric technology are widely accepted and described in various research studies [8]. This strategy allows a reduction of pollutant gases produced by conventional vehicles, but this would depend on strategic planning and the percentage of vehicles to be substituted. Intermodal transport policy, from private cars to public transport, decreases pollutant gases and congestion by reducing private car trips to the city center [9]. The intermodal transport point is known as the park and ride (P&R) system. P&R helps private car users to drive a certain distance, park their private vehicles, and then travel to the city center via public transport [10]. Thus, the P&R system is a modal interchange point, which through the promotion of public transport, reduces the adverse impact of private vehicles on central business district (CBD), such as congestion and pollution [11]. Autonomous vehicles are involved in a third policy or strategy that is relatively new, particularly concerning medium-sized cities. It has already been proven that pollutants are reduced by intelligent drive modes [12,13]. The amount of emissions that can be minimized depends on the percentage of autonomous vehicles that a city government has implemented as a long-term strategy [14,15].

In terms of the policies mentioned above, substantial research has already been carried out on a city scale to reduce pollution levels. However, implementing those policies or strategies to assess the emission reduction percentage helps local governments in the decision-making process. The combination of transportation policies has been studied over time. However, they have evolved to include the implementation of autonomous vehicles. Previous research has not investigated the policies that combine P&R, autonomous, and electric vehicles. Furthermore, these policies can also be evaluated separately and in combination to reveal which combination is the most suitable one to apply over time.

The environmental impacts of transport are also herein discussed. Greenhouse gas (GHG) emissions are growing each year. GHG emission increased by an average of 1.1% in 2019, with a total of 52.4 gigatons of CO_2 equivalent compared to 22.5 gigatons in 1900 [16]. This increase in emissions will result in the acceleration of climate changes, leading to catastrophic consequences for our civilization. The transportation sector is responsible for consuming 27% of global energy demand and resulting in 14% of total global GHG emission [17], of which 72.8% is emitted from road transport [18]. Reducing the amount of fuel consumed by road transport will significantly reduce the amount of emissions produced by the transportation sector in total. The total number of daily trips, the amount of fuel consumed by each vehicle, or both have to be achieved to reach this. Several measures have been initiated to improve fuel economy and reduce emissions of on-road vehicles. These include improving fuel quality and the introduction of renewable fuels [19], new vehicle technologies [20], and more strict road emissions standards [21,22].

Therefore, this article aims to determine through the construction of scenarios each strategy or policy. Then, combinations of scenarios are tested in order to find the most practical transport policy for reducing the pollution caused by private vehicles. In order to achieve this objective, a case study is taken into consideration for the city of Cuenca, Ecuador. Their authorities developed a SUMP that is used as a data collection instrument for this study, and also the policies for the location of a P&R system and electric vehicles are available [23–26]. Moreover, autonomous vehicles are relatively new in Latin American cities and, therefore, the researched literature is regarded as a guide. The COPERT software is used to calculate the percentage of emissions by applying transport policies. This article is structured as follows: Section 2 describes the literature concerning pollutant gases with respect to electric vehicles, autonomous vehicles, P&R, and the software used to calculate emissions. Section 3 explains in detail the methodology used. Section 4 presents the results established from the case study with their respective scenarios. Section 5 discusses the results obtained. Finally, in the conclusion, the authors describe the contribution of this study, its limitations, and future research recommendations.

2. Literature Review

This section offers an overview of the work on the three types of pollution reduction policies in the urban environment and the software used to measure the environmental components of pollution.

2.1. Autonomous Vehicles(AVs)

Autonomous vehicles (AVs) depend on both automation levels of the Society of Automotive Engineers (SAE) present in the traffic stream and the percentage of AVs in the total traffic flow (AV penetration). AVs will decrease or even totally eliminate human factors from traffic flow, which are believed to increase road capacities' resulting in less congestions [27]. Studies on motorways in the USA showed that automated vehicle penetration of 90% of the total traffic would reduce both delay and fuel consumption by 60% and 25%, respectively [28]. A Tokyo city model study showed that AVs are expected to replace about 7–10% of conventional vehicles [29]. Another study found that AVs programmed to operate in the eco-driving fully (which is a modern way of driving that improve vehicle fuel consumption efficiency, safety, and speed) mode reduced fuel consumption by 10–20% [30]. The initial estimations on GHG emission reduction for AVs can be expected from a minimal impact to 80% reduction by 2050 for light-duty vehicles. The most significant emission reduction by AVs is the change in the mobility model [31,32]

As mentioned above, fuel consumption can be reduced by eco-driving, which is faster and has relatively lower costs than changing the whole fleet to more advanced vehicles [33,34]. Eco-driving showed an improvement in fuel efficiency by up to 45% [35]. El-Shawarby et al.'s study proved that aggressive driving compared with defensive driving, increase fuel consumption by 50%, 3% increase in CO_2, 20 times more CO, six times more HC, but lowered NO_x by 65% [36]. MacKenzie's study found a 1% reduction in acceleration rate from 0 to 60 mph reduced fuel consumption by 0.44%, showing that it would be better to reduce fuel consumption than to increase engine power and acceleration [37]. Lower following distance between vehicles with intelligent driving also proved to reduce fuel consumption [38]. Another aspect of eco-driving is using navigation systems to improve fuel consumption. The shortest or fastest route is not always the best choice in fuel consumption and emissions [14,39,40]. Ericsson et al.'s study found that 46% of driver-chosen journeys were not the most fuel-efficient routes, and using fuel-optimized navigation systems saved up to 8.2% in fuel consumption [41]. A more efficient air conditioning system, lighter vehicles, tire pressure, and vehicle maintenance are also factors that affect eco-driving and result in high fuel efficiency [35,42,43].

2.2. Electric Vehicles (EV)

Electric vehicles (EV) offer another solution to reduce GHG emissions in the transport sector. EVs are still considered zero-emission vehicles by the European law, even if the indirect emissions associated with electricity production might be high [14,44]. Shen et al. show that the benefits of battery electric vehicles (BEVs) will be significant with 60–70% lower emissions than that of internal combustion engine vehicles, and 10–40% lower than 2030 advanced hybrid electric vehicles (HEVs) [45]. Several studies conducted well-to-wheels (WTW) analysis to compare EVs and different types of vehicles. Ke et al. found that BEVs can significantly reduce WTW carbon dioxide emissions compared with conventional engine vehicles [46]. Orsi et al.'s WTW analysis showed that EVs could produce nearly zero CO_2 emissions, but their cost remains significantly higher than that of conventional vehicles and HEVs [47].

2.3. Park and Ride (P&R)

The P&R system is seen as a place for modal shift that effectively reduces private vehicle travel and promotes public transport. The private users of vehicles drive a certain distance to make a modal change in the P&R system to a more sustainable transport mode, such as public transport, to reach their destination [48,49]. As a result, the widely used urban planning concept for determining a P&R facility's location has been to place them near public transport stations to promote transfers from private car users to the public transport system [50–52]. Farhan and Murray proposed a mathematical optimization model that selects the optimum set of facilities in a city that considers covering as many potential users as possible and placing P&R facilities close to public transport [53]. Moreover, multi-criteria methods have been applied to define which criteria are the most important ones for the location of P&R facilities, resulting in the accessibility of public transport [23,24,26,54].

2.4. COPERT Software

COPERT software is a model developed by the European Environment Agency for macroscale vehicle emissions and statistically analyzes the distribution of technical level, activity characteristics, and vehicle operating conditions [55]. For example, CO, CO_2, NO_x, and PM emissions of heavy-duty diesel passenger buses were calculated using the COPERT model in Hainan Province. The results show that the emission reduction standard will reduce CO, CO_2, NO_x, and PM emissions by approximately 23%, 12%, 23%, and 46%, respectively [56]. The software is based on the basic emission factors and displays vehicles' emissions from various countries and regions. It also combines a mathematical model capable of calculating emissions from statistical data on emission sources at the country level. The case study focuses on Cyprus and investigates the application of specific climate change mitigation scenarios. The main results of the study show that increased use of biomass and diesel can promote decarbonization, but fails to reduce air pollution, while hybrid technologies and natural gas offer significant improvements for both objectives [57,58]. Research was carried out with COPERT to evaluate the effect of current and future greenhouse gas mitigation policies on CO_2 emission models on the fleet of passenger vehicles and other types of road transport from 2015 through 2035 [59]. A COPERT approach for estimating traffic emissions at the micro-scale, with direct application in regional and urban emission inventories, and the FOREMOVE model, developed for forecasting motor vehicle emissions, is presented, together with some results of its application in the European Auto/Oil program. The results show the main areas for future research in the field of vehicle emissions in Europe [59,60]. A study in Australia showed that the COPERT software for CO, NO_x, and PM2.5 was precise at vehicle fleet levels [61].

Identifying which policy or combination of policies provides the best emission reductions in the urban environment is still problematic. Nowadays, many measures and policies focus on reducing greenhouse measures in addition to the described ones, such as shifting to active travel, e-commerce or smart working. Besides, SUMPs define future mobility policies. A mobility policy in smart cities of the future will be the implementation of autonomous vehicles. However, there are also existing transportation infrastructure and even policies to reduce emissions, such as implementing electric vehicles and using the P&R system. There is a gap in the literature review on how autonomous vehicles combined with other mobility policies can reduce pollutant emissions. Using the SUMP as a data collection method, we developed a methodology to propose these mobility policies and use software that calculates contaminants' emissions. The result will provide a tool for planners and researchers on mobility policies to be drawn in the future on the reduction of pollutant emissions by implementing autonomous vehicles.

3. Method

This section describes the approach used, including a description of the case study and an overview of the SUMP and transport policies regarding parking, electric cars, autonomous vehicles, and other urban features. Even though the SUMP has provided guidelines for electric vehicles and parking, the introduction of autonomous vehicles in Latin American cities is still a new idea, and as such has not been included in the SUMP discussed here. The autonomous vehicles in the mobility plan of Cuenca have not been included as a mobility policy because the main objective in the year was to promote mobility and connectivity on pedestrian and public transport. Besides, autonomous vehicles were a new technology in Ecuador at that time. However, in the new SUMP update, it is advisable to include autonomous vehicles. In this context, it is essential to use specific data from the available literature. The remainder of the section addresses how to use the COPERT software. Details about how the program is structured with tiers are given, and it is discussed why those tiers were taken into account in the study.

3.1. Overview of the Study Area

Cuenca is located in southern Ecuador, with 330,000 inhabitants. A SUMP was developed in 2014 for the city with the objective of offering citizens a city with short-, medium-, and long-term mobility policies and strategies that allowed them to live in an environmentally friendly city. The SUMP is a tool that serves as a method for planners and researchers to collect data that can be used in future studies. Besides, it establishes the city's transport policies for the future [62]. The aim is to provide citizens with a more sustainable city through a set of transportation policies and provide solutions to the adverse impacts of the private automobiles, such as congestion and pollution, especially in the city centre. According to the SUMP, the city has been divided into 15 zones or districts. Zones 5–7 are considered to be the CBD. Ortega et al. initially conducted a series of studies analyzing the P&R system in Cuenca. The data on origin-destination trips from the different areas to the CBD can be obtained from the SUMP [61,62]. The urban mobility in Cuenca involves about 600,000 trips per day to and from the city center. Among them, 69% are motorized trips, and 31% correspond to pedestrians and cyclists. Private cars account for 32% of the trips recorded in Cuenca. In the city center, 42,768 trips are made by private cars, which correspond to 20% of the total trips in the urban area. The composition of vehicles and bicycles is distributed as follows: 90.08% are private vehicles, followed by 3.52% buses, 2.70% freight transport, 3.70% bicycles and the rest other modes of transport. The vehicle inventory of the city of Cuenca is composed of 147,484 vehicles. The pollution produced in the city is divided into 57% from vehicles, 16% from industry, 5% from energy production, 16% from housing and services 6% from residues. Regarding traffic pollution, the different components compared to full emission in the city are as follows: carbon dioxide (CO_2) 70%, carbon monoxide (CO) 94.5%, nitrogen oxides (NO_x) 71.2%, sulfur dioxide (SO_2) 30.2%, fine particulate matter (PM2.5) 42.5%, fine particulate matter (PM10) 55.6%.

The air quality in the city of Cuenca is mostly in the "good" category and can be verified at the following link [63].

3.2. Methodology for the Calculation of Emissions

The computer software developed by the European Environment Agency called COPERT is used to measure private car emissions. The analysis of emissions in the program is illustrated in detail in Figure 1 [64].

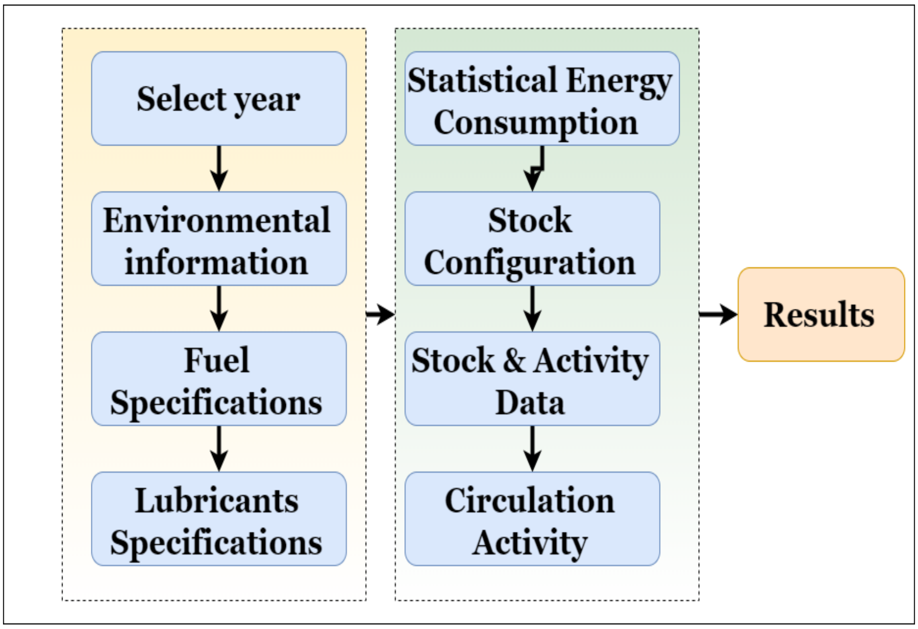

Figure 1. COPERT model estimation procedure [56,64].

- Select the year: Select the year for which the study is intended to be carried out.
- Environmental information: The city's meteorological information such as recorded temperature, the relative humidity for a year.
- Fuel specifications: Fuel values such as density (kg/m^3), percentage of fuel aromatic components in PCA (% v/v), and NC cetane number can be entered.
- Lubricant specifications: information is pre-installed within the software.
- Statistical energy consumption: compares statistical and calculated energy consumption, modifies a number of input data (e.g., mileage, blend share), and recalculates emissions
- Stock configuration: The type of vehicles that make up the city's vehicle fleet.
- Stock and activity data: The number of vehicles by category and kilometers travelled.
- Circulation activity: Urban trips are selected, which are the vehicles that are being investigated.

The methodology for estimating emissions by the COPERT program covers exhaust emissions of CO, NO_x, NMVOC, CH_4, CO_2, N_2O, NH_3, and SO_x. The following decision tree (Figure 2) was developed by Leonidas Ntziachristos et al. [65,66], which gives us an idea of what outcomes to expect.

The COPERT software, depending on the data and the purpose of being calculated, operates three Tier types. For example, to calculate the emissions given the kilometers traveled, the type of vehicle and the technology used for European Environment Agency (NFR), and the average driving speed, the program will use the equations belonging to Tier 3, based on the vehicle's activity. Road transport is very probably a key category in all countries. Therefore, efforts should always be made to use a tier 2 or 3 method for road transport emission estimation.

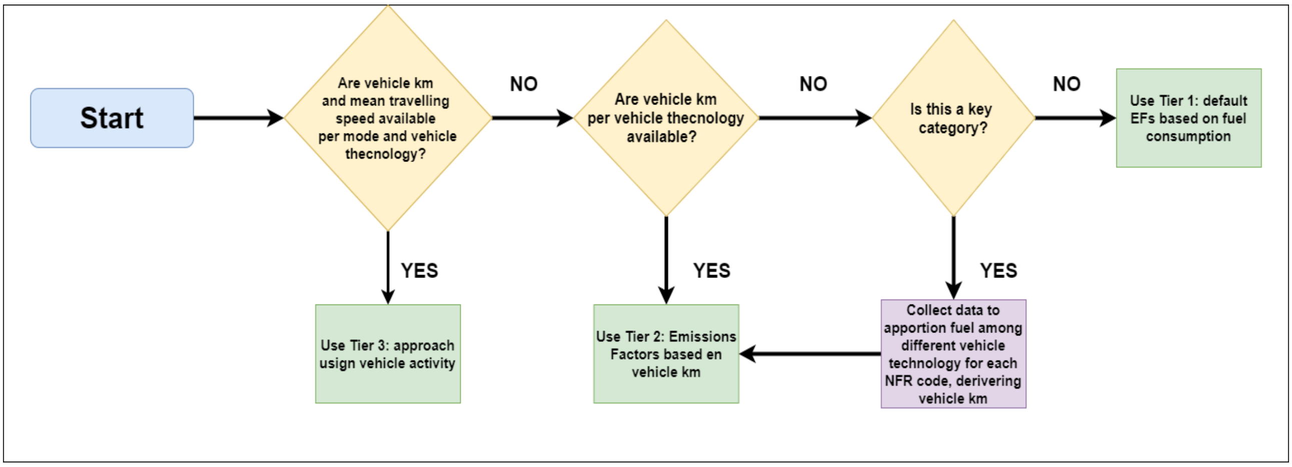

Figure 2. The decision tree for COPERT [65–67].

The equations for each tier to calculate pollutant emissions are explained in the following.

- Tier 1

Algorithm for calculating the general exhaust emissions is:

$$E_i = \Sigma_j \left(\Sigma_m \left(FC_{j,m} \times \Sigma\, EF_{i,j,m}\right)\right) \quad (1)$$

where:

E_i = Emission of pollutant i [g];

$FC_{j,m}$ = Fuel consumption of vehicle category j using fuel m [kg];

$EF_{i,j,m}$ = Fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m [g/kg].

The equation considers different vehicle classes (PC, LCV, HDV, and L-category vehicles), which require fuel consumption/sales statistics to be split by vehicle classes.

The Tier 1 approach requires related fuel data, volumes of fuel sold for road transport use, and the sales volumes are separated among the four vehicle classes. This means the sum of each type of fuel sold is equal to the sum of the fuel consumed by the four different classes:

$$FC_m = \Sigma_j \left(FC_{j,m} \right) \tag{2}$$

- Tier 2

According to emission control laws, the Tier 2 methodology subdivides the four main vehicle classes into sub-classes with different emission standards and into different technologies k. Tier 2 uses the kilometers travelled for each vehicle subclass divided by the emission factor for each subclass.

$$E_{i,j} = \Sigma_k \left(\left\langle M_{j,k} \right\rangle \times \Sigma EF_{i,j,k} \right) \tag{3}$$

or

$$E_{i,j} = \Sigma_k \left(N_{j,k} \times M_{j,k} \times EF_{i,j,k} \right) \tag{4}$$

where:

$\langle M_{j,k} \rangle$ = Total annual distance driven by all vehicles of category j and technology k [veh-km];

$EF_{i,j,k}$ = The technology-specific emission factor of pollutant i for vehicle category j and technology k [g/veh-km];

$M_{j,k}$ = Average annual distance driven per vehicle of category j and technology k [km/veh];

$N_{j,k}$ = Number of vehicles in the nation's fleet of category j and technology k.

Tier 2 traffic data are usually available from the national statistics offices of each country. International statistical organizations also provide such data. The COPERT website provides detailed data for both vehicle stocks for all EU-28 and annual distance driven per vehicle class.

- Tier 3

In Tier 3 methodology, emissions are calculated using a combination of fixed technical data and activity data. The methodology is to estimate the summation of hot emissions and cold emissions. Hot emissions are pollutants that emits when the engine is operating at an average temperature. Cold emissions are pollutants that are emitted during the warming up of the engine. Calculation of cold emissions is essential, since the concentration of emissions of some pollutants is much higher during the warming-up phase.

$$E_{TOTAL} = E_{HOT} + E_{COLD} \tag{5}$$

where:

E_{TOTAL} = Total emissions [g] of any pollutant for the spatial and temporal resolution of the application;

E_{HOT} = Emissions [g] during stabilized (hot) engine operation;

E_{COLD} = Emissions [g] during transient thermal engine operation (cold start).

A different equation to calculate emissions is to consider driving conditions of the road type is shown in the equation below; where E_{URBAN}, $E_{RURAL,}$ and $E_{HIGHWAY}$ are the total emissions in grams of any pollutant for the particular driving conditions.

$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \tag{6}$$

Hot emissions depend on several factors (distance travelled, speed, vehicle age, power, and weight of engine).

$$E_{HOT:i,k,r} = N_k \times M_{k,r} \times e_{HOT:i,k,r} \tag{7}$$

$$e_{HOT:i,k,r} = \int \left[e(V) \times f_{k,r}\ (V)\right] dV \tag{8}$$

where:

$E_{HOT;i,k,r}$ = Hot exhaust emissions of the pollutant *i* [g], produced in the period concerned by vehicles of technology *k* driven on roads of type *r;*

N_k = Number of vehicles [veh] of technology *k* in operation in the period concerned;

$M_{k,r}$ = Mileage per vehicle [km/veh] driven on roads of type *r* by vehicles of technology *k;*

$E_{HoT;i,k,r}$ = Emission factor in [g/km] for pollutant *i*, relevant for the vehicle technology *k*, operated on roads of type *r*;

V = Total emissions [g] of any pollutant for the spatial and temporal resolution of the application;

e (V) = Emissions [g] during stabilized (hot) engine operation;

$F_{k,r}$ *(V)* = Emissions [g] during transient thermal engine operation (cold start).

Cold emissions are calculated as an additional emission over the expected emissions of warmed-up hot engines. For the calculation, a factor is applied to the driven vehicle mileage in the cold engine condition. The factor is affected by the climate and temperature conditions and time required to warm up the vehicle. The equation below is used to calculate cold emissions.

$$E_{COLD:i,\,j} = \beta_{i,\,k} \times N_k \times M_k \times e_{HOT:i,\,k} \times \left(e^{cold} / \left. e^{HOT} \right| i, k-1\right) \tag{9}$$

where:

$E_{COLD;i,k}$ = Cold-start emissions of pollutant *i* (for the reference year), produced by vehicle technology *k*;

$\beta_{i,k}$ = The fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature for pollutant *i* and vehicle technology *k*;

N_K = number of vehicles [veh] of technology *k* in circulation;

M_K = Total mileage per vehicle [km/veh] in-vehicle technology *k*;

$e_{HOT:i,k}$ = Hot emission factor for pollutant *i* and vehicles of *k* technology;

$e^{COLD}/e^{HOT}\mid_{i,k}$ = Emissions [g] during stabilized (hot) engine operation.

3.3. Selected Scenarios

The methodology is applied to three main scenarios.

- Scenario I

Autonomous vehicles (AV): Starting from the hypothesis that the existing fleet of conventional vehicles is replaced by autonomous vehicles concerning three empirical percentages. For this article, 20% was chosen [68].

- Scenario II

Autonomous electrical (AEV): Here autonomous electric are supposed to replace 20% of traditional vehicles.

- Scenario III

Autonomous vehicles using P&R (AV+P&R): This represents the replacement of 20% of conventional vehicles by autonomous vehicles, and a proportion of the whole vehicles fleet is supposed to use P&R facilities. This modifies the modal split, and reduces trips to the city center, which according to several studies can be 10%, 17%, and 20%, respectively [23,69,70]. For the aim of this study, 17% reduction of trips was used.

- Scenario IV

Autonomous electrical vehicles using P&R (AEV+P&R): This represents the replacement of 20% of conventional vehicles by autonomous vehicles, with a 17% reduction of trips due to P&R.

The final objective is to determine which of the scenarios represents a future transport policy for reducing pollution in a city's urban environment.

4. Results and Discussion

The results produced by the COPERT program are shown below in Figures 3–5. The first column is the real data stipulated in the SUMP of the city, and the second column is the data calculated by the software under the same conditions using the current traffic situation (volume of vehicles, composition, and driven kilometers). Then, the results of the scenarios are shown. As a first conclusion, the result obtained through the COPERT program's calculation is similar to the SUMP, which uses information from stations located throughout the city.

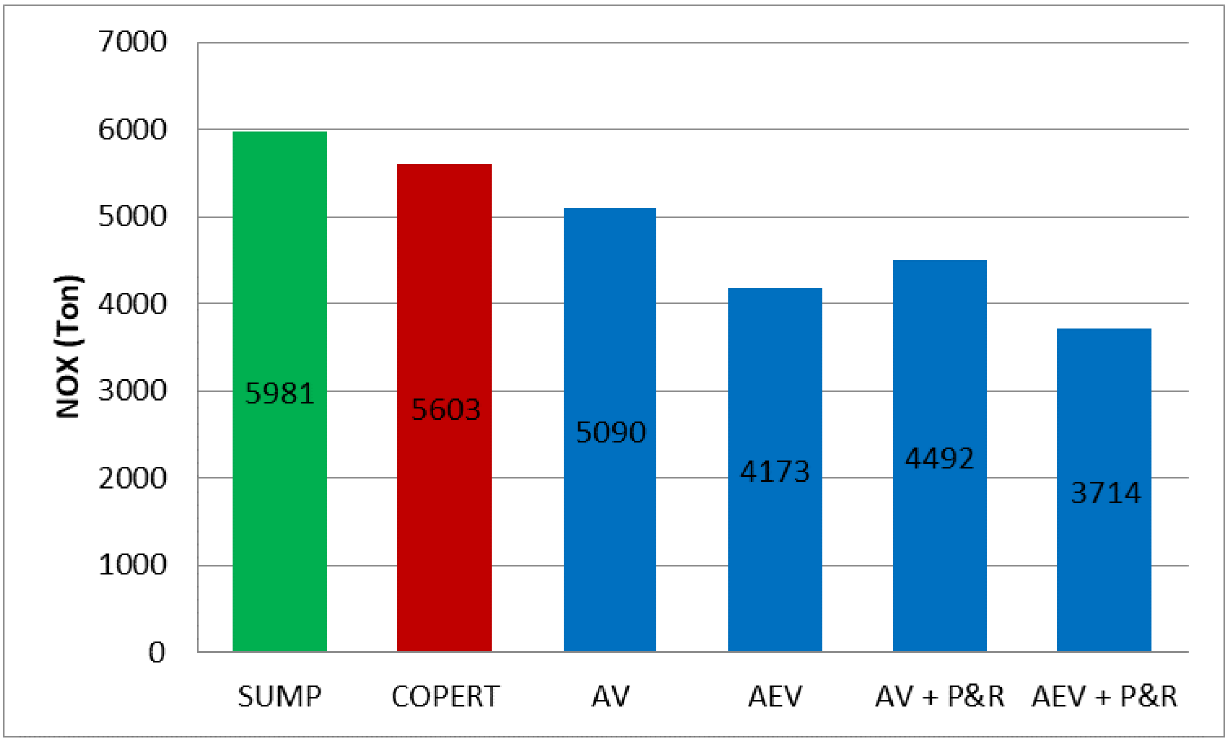

Figure 3. NOx value for each scenario.

Figure 3 shows the results obtained from the SUMP, COPERT, and the scenarios proposed with respect to NO_x.

The difference between NO_x COPERT estimation and SUMP collected real life data emissions was 6.32%. The slight change proves that COPERT is efficient in NO_x calculations. Figure 4 shows the results obtained from the SUMP, COPERT, and the scenarios proposed with respect to CO.

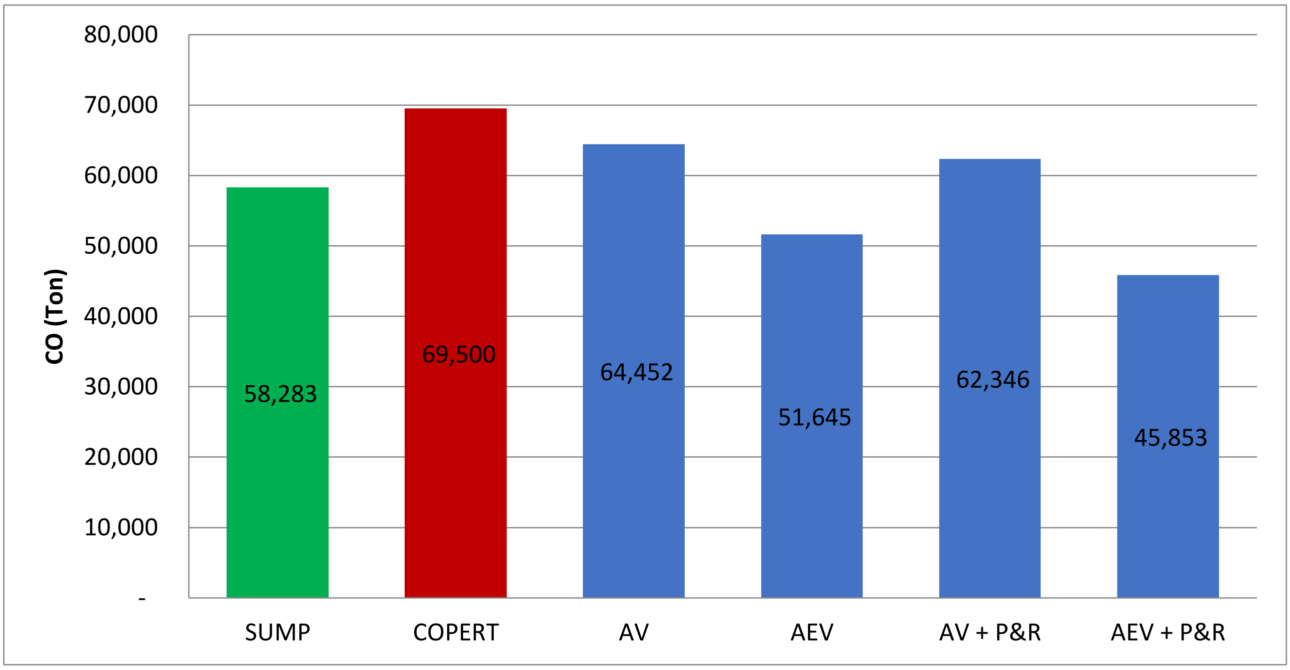

Figure 4. CO value for each scenario.

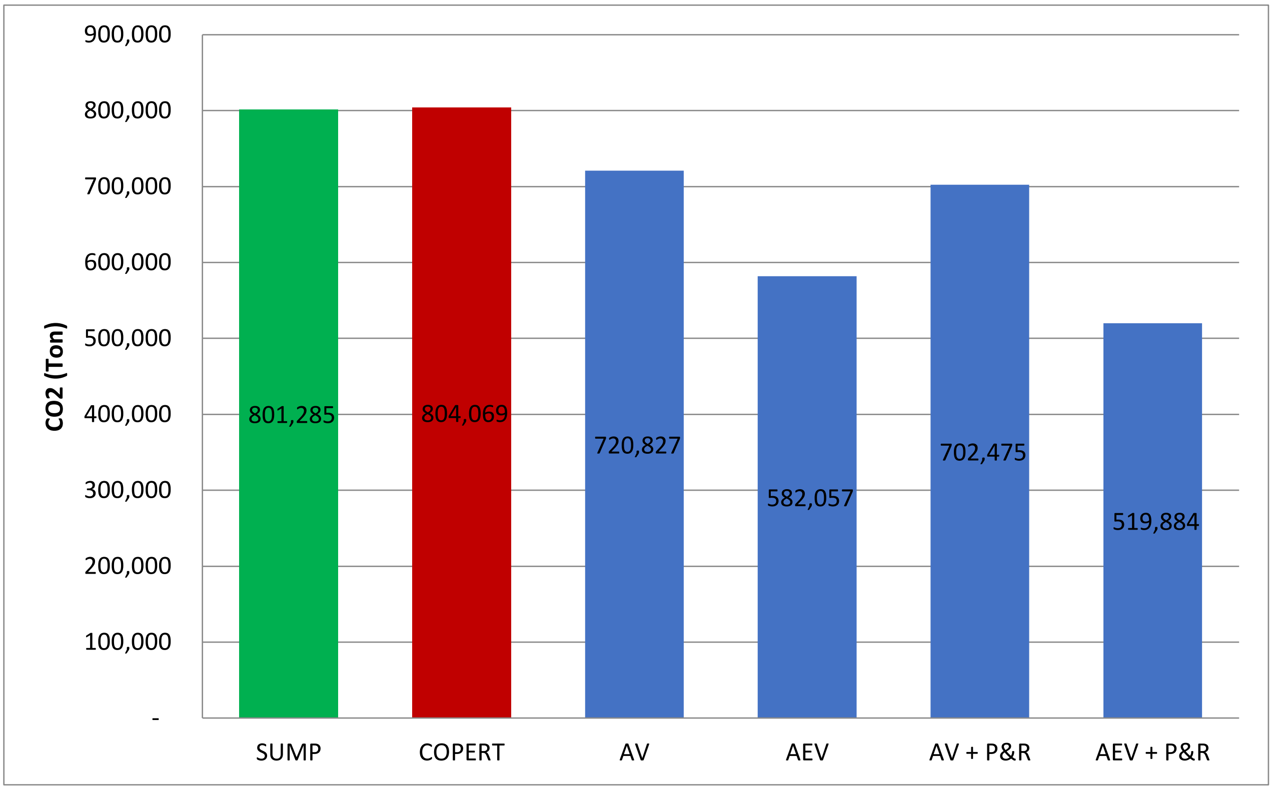

Figure 5. CO_2 value for each scenario.

For CO emission estimation, COPERT resulted in a considerably large error of 19.25% which was an increase compared to the SUMP CO value. This can be improved upon by choosing a more suitable CO factor for the study area characteristics in the COPERT software. Figure 5 shows the results obtained from the SUMP, COPERT, and the scenarios proposed with respect to CO_2.

COPERT CO_2 calculation resulted in only a 0.35% error compared to SUMP real life data, proving a high accuracy in CO_2 estimation.

Concerning the first scenario, the introduction of autonomous vehicles in a city theoretically decreased fuel consumption and, therefore, this option can be added in COPERT in the fuel consumption section. Thus, an average of 25% reduction due to intelligent driving gives the best value. According to several studies [30,34,35], 25% fuel reduction was used for autonomous vehicles class.

Concerning the incorporation of autonomous electric vehicles in the COPERT program, Scenario 2 reduced the total number of vehicles by electrical vehicle percentage since electrical vehicles have zero emissions. Therefore, the pollution reduction in Scenario 2 is much more effective than in Scenario 1. However, this policy depends on the percentage of vehicles to be replaced.

Scenarios 3 and 4, which involve autonomous vehicles and electrical vehicles using the P&R system, allows the COPERT software to reduce the number of trips. The result is that pollution is reduced by adding a P&R system to be used by autonomous vehicles and all other vehicle classes. The reduction of each considered emission for each scenario compared with COPERT baseline results is shown in Table 1 below.

Table 1. Emissions reduction percentage for each scenario.

Scenario		CO	NO_x	CO_2
Base	(Tons)	69,500	5603	804,069
I	AV	7%	9%	10%
II	AEV	26%	26%	28%
III	AV + P&R	10%	20%	13%
IV	AEV + P&R	34%	34%	35%

A comparison between scenarios reveals which policy is the most effective, and their combinations can also be tested. Thus, the first scenario, which introduces autonomous vehicles, improves environmental conditions by reducing pollution. The second scenario had a significant improvement, reaching around 26% for the three pollutants. However, by comparing autonomous electric vehicles and autonomous vehicles when using the P&R system, P&R was seen to have a big impact on reducing the three considered emissions. The policy that will help reduce pollution most strongly is the one that leads to a mode shift from transport to a more sustainable mode, such as the public transport system through the P&R system. While the transition to autonomous electric vehicles may take a long time to implement due to the need of large changes in traffic fleet and infrastructure, the change into autonomous vehicles is easier. Another advantage is that P&R system is already in place in some cities. Therefore, the focus is on getting users of to use the P&R system. This is a powerful policy in the future to reduce pollution levels.

5. Conclusions

Future policies need to include autonomous vehicles and how they interact with the planning and infrastructure in a given area or settlement. Moreover, it is worth considering the introduction of autonomous (electric) vehicles and the shift to more sustainable transport modes over time, such as public transport. All of these policies are objectives set out in mobility plans. They help determine how the level of pollution can be reduced. The COPERT program can estimate the percentage of pollution reduction in the CBD if the number of trips in different ways is reduced. In this article, a case study was presented for the city of Cuenca in Ecuador to verify the model's efficiency, and the SUMP of the surveyed settlement was used as a source of data.

According to the results, implementing autonomous vehicles mitigated traffic pollution by an average of 9% for the three considered pollutants. The second scenario involving electric and autonomous vehicles reduced the number of conventional vehicles using petrol. Therefore, it showed significant mitigation of around 26% reduction in three total emissions. Scenarios three and four were even more effective, as these scenarios used the P&R system and autonomous vehicles. It must be noted that, as the P&R is already established in some cities, it is worth exploiting it, as the spread of autonomous vehicles is still underway. While scenario four has proven the best with an average of 34% reduction, it still requires some time to change and prepare the infrastructure to spread electric vehicle's new technology.

This study only focused on private transportation due to insufficient data on the public transportation sector. Future research will have to include autonomous vehicles in much of the infrastructure and explore policies concerning integrated transport systems.

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