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Impact of electric trucks in GHG inventory – A Uruguayan scenario study

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Abstract

This paper aims at studying the status of the current fleet of freight vehicles that travel through Uruguay, following international methodologies for calculating GHG gas emissions to determine the current inventory of gases caused by road freight transport. This inventory acts as a starting point to establish three future scenarios where different alternative powertrain technologies are implemented at different rates, such as battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV). The transition from Euro III regulations into Euro V is also considered for these scenarios. Based on these future scenarios, it is possible to project the levels of future emissions that Uruguay will perceive in a time horizon that reaches the year 2050. This study aims to increase the level of information present in the region on the emissions generated in the road freight transport sector, providing new input to the development of future policies on these issues.

Keywords: GHG inventory, road freight transport, electric trucks, alternative powertrains

1 Introduction

With its heavy consumption of petroleum products, the road freight transport sector is a major emitter of carbon dioxide globally. Its emissions are estimated at 2,861 Mt CO_2 (Megatons of carbon dioxide), 8.1% of all CO_2 emissions generated by fuel consumption in the world (Welch et al., 2020). It is a sector that stands out for generating large emissions compared to the small number of vehicles that compose it since it is composed of only 4% of the vehicles that circulate on the streets. This is even more pronounced in the case of trucks with more than 3.5 tons of cargo. In 2018, among buses, light, medium, and heavy trucks, the latter two (>3.5 tons of cargo) were 30% of the total in units worldwide but generated 62% of emissions. Therefore, this small group is responsible for most of the emissions of the sector (IEA International Energy Agency, 2020a, 2017; Shell and Deloitte, 2021).

This sector has committed to focusing on alternative technologies that can replace conventional internal combustion engine vehicles because of their potential to reduce greenhouse gas emissions (Breuer et al., 2021; Mojtaba Lajevardi et al., 2019; Sen et al., 2016; Zhou et al., 2017). Among the technologies of vehicles with alternative energies, battery electric vehicles (BEV) and hydrogen electric vehicles, which are fuel cell electric vehicles (FCEV) stand out. On the one hand, BEVs have battery packs that store the electricity needed to drive the electric motor. On the other hand, FCEVs are also powered by electricity but store their energy in the form of hydrogen, which is converted from chemical reactions (Smart Freight Centre, 2020).

The global concern upon the negative impact of greenhouse gases emissions also occurs in both Latin America and Uruguay. In Latin America, the transport sector is also the largest responsible for CO_2 emissions (IEA International Energy Agency, 2019). For its part, according to Uruguay's 2020 National Energy Balance (BEN), the transport sector, which includes both individual and collective mobilization of people and cargo by air, land, and water, has historically been and continues to be, the largest generator of CO_2 emissions, among all energy industries and their consumers. Since 2006, emissions produced by this sector have been growing, the main cause being gasoline consumption, which increased by 145% in this period. It should be noted that there was a small reduction in emissions in 2018 and another of 6% in 2020. In 2020, the emissions of this sector caused by the use of fuels were 3.514 kilotons of CO_2, being approximately 57% of the total emissions of the country of that year (MIEM, 2020).

Even though Uruguay only accounts for 0.04% of global CO_2 emissions, it is a country that is highly affected by climate change because the basis of its economy is agricultural. It is for this reason that, in December 2021, Uruguay published a Long-Term Strategy for Low Emissions and Climate Resilient Development with which it seeks to combat the increase in emissions in all sectors to achieve CO_2 neutrality in 2050 (Uruguay Presidencia, 2021). When it comes to Latin America, a study made by the ICCT (ICCT, 2022a) states that Chile also announced a National Electromobility Strategy in 2017, which has similar milestones to the Uruguayan one: by 2035, all urban busses and light and medium vehicles sold must be zero-emissions and by 2045, all heavy-duty vehicles and intercity busses must also be zero-emissions (ICCT, 2022a). The same study analyses other countries zero-emission sales targets and states that neither Brazil, Colombia, Costa Rica, Ecuador, and Mexico have targets regarding medium and heavy-duty vehicles and that only Colombia, Costa Rica and Ecuador have targets regarding urban buses and intercity buses (ICCT, 2022a). Other nations across the globe also presented their long-term strategies. For example, the

European Union presented a plan in March 2020, which aims to achieve climate neutrality by 2050. For its part, China presented its strategy in October 2021 and the United States in November of the same year (European Commission, n.d.; UNFCCC, n.d.). Although in developed countries these strategies include measures to reduce emissions from trucks, they need to be more ambitious to achieve the objectives of the Paris Agreement (Shell and Deloitte, 2021).

Due to the need to link adoption of zero-emission vehicles for road freight and the impact on CO_2 emissions (Alonso et al., 2010; Mojtaba Lajevardi et al., 2019; Sen et al., 2016), this study seeks to contribute by generating valuable information regarding emissions in Uruguay and contrasting and complementing information generated in the Latin American region. The main objective and contribution of the study is to present and analyse scenarios in which different emission reduction strategies are applied. These strategies include the use of new technologies, and a correct analysis of how new technologies reduce emissions is essential to promote or discourage their use.

A previous study focused on the breaking point of electric trucks in Latin America revealed that both Uruguay and Chile are leading efforts in achieving total cost of ownership (TCO) parity between battery electric trucks BEV and internal combustion trucks (ICEV) (Tanco et al., 2019b). The TCO is one of the key factors examined when comparing BEVs and ICEVs economically, since it considers every expense made over the course of a vehicle's life, giving potential buyers a tool for decision-making (Tanco et al., 2019b). These results are strong motivators to conduct this study focused on Uruguay. The country also presents favorable conditions for the development of electric transport in terms of generation and infrastructure as 95% of the energy matrix is renewable (on average from 2016 to 2021), highlighting generation from wind, solar, hydro and biomass (MIEM, 2021).

Currently, measures are already being taken to implement these technologies, but it will be useful to quantify their impact to define in which to deepen their promotion. About BEVs, progress is being made in their incorporation into public transport with buses and taxis (Proyecto MOVÉS, 2021). However, medium-sized electric trucks are just beginning to be adopted in companies. On the other hand, although FCEVs are not yet commercially available, in 2021 a pilot project was started in Uruguay for the production of green hydrogen, which is one of the first steps to consolidate the country as a supplier and exporter of this product (ANCAP, 2021). This project includes a plan for heavy transport, which seeks to attack current energy challenges, such as the dependence on fossil fuels in the industrial sector.

This research assesses the current inventory of emissions of five gases (CO_2, N_2O, CH_4,NO_x and CO) caused by road freight transport in Uruguay by using widely applied calculation methods proposed by IPCC (IPCC, 2006). The road freight transport, which is the scope of this study, considers light, medium and heavy-duty trucks. Three future scenarios of how BEVs and FCEVs will be inserted into the global road freight were applied in Uruguay to project the levels of future emissions and provide information that can support the development of future policies. Forecasts show that Uruguay needs of greater efforts to meet its goals and combating climate change.

The remaining parts of this study are structured as follows. First, section 2 presents a literature review of 2the subject. Then, section 3 explains the methodology used to calculate the emissions of the sector, section 4 presents the calculation of emissions of polluting gases, and section 5 analyses projections of scenarios of insertion of technology in Uruguay. Subsequently, section 6 shows the discussion and section 7 the conclusions.

2 Literature review

The freight transport sector is fundamental to the development of economies (Ramachandra and Shwetmala, 2009). However, this sector is one of the main causes of the increase in air pollution, mainly due to GHG emissions (Policarpo et al., 2018).

Pollutant emissions and fuel consumption are mainly due to the type of transport, the fuel used, the combustion engine technology, the age of the vehicle, and the maintenance procedures carried out (Policarpo et al., 2018; Ramachandra and Shwetmala, 2009). In addition, emission levels can be affected by factors related to vehicle driving, such as the number of accelerations, sudden stops and the type of road (Policarpo et al., 2018). However, the most influential variable in annual emissions in a country is the distance traveled by these vehicles (Bebkiewicz et al., 2021).

There are numerous fuels used in the transport sector, such as diesel, naphtha, liquefied petroleum gas, natural gas, biofuels, and electricity, among others. Within the fossil fuels used for transport, naphtha and diesel are predominant for cargo transport (EEA, 2015; Rodrigue, 2020). The first of these is found in light vehicle applications and, the second, is predominantly in heavy vehicles (EEA, 2015). The chemical combustion reaction that takes place in the engine of internal combustion vehicles (ICEV) has as main products carbon dioxide (CO_2) and water (H_2O) (EEA, 2015). However, because this reaction is not complete, you have by-products such as carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) (EEA, 2015). In addition, there is oxidation of non-combustible elements that give rise to emissions of nitrogen oxides (NO_x), due to nitrogen (N_2) present in the air, and sulphur oxides (SO_x), due to the sulphur present in lubricants (EEA, 2015; Ramachandra and Shwetmala, 2009). In addition to the exhaust emissions from the combustion reaction, there are other emissions involved in transport due to fuel evaporation, tyre wear, brakes and road wear (EEA, 2015).

Since 1970 there has been European legislation to control the emissions of vehicles in the sector and since 1992 the "Euro" standards are mandatory in the European community (EEA, 2015). Increasingly stringent regulations forced vehicle manufacturers to continuously improve engine technology while introducing emission control systems into vehicles (EEA, 2015; Policarpo et al., 2018). The most recent standard corresponds to Euro VI and reduces some of the pollutants by up to 96% compared to the limits established in 1992 (Automobile Association, 2017). Additionally, the European Union is developing the next emissions standard, Euro VII, and aims to implement it in 2025 (Transport & Environment, 2021). This standard aims to significantly reduce emissions, which will force manufacturers to improve the efficiencies of engines and emission control systems (Transport & Environment, 2021).

In addition to regulations and emission restrictions, there are other alternatives to reduce air pollution that includes the use of vehicles with biofuels, electric, vehicles and hybrid vehicles (EEA, 2015). For freight transport, the technologies that are mainly being discussed to address climate change in this sector are battery electric trucks and fuel cell trucks (Breuer et al., 2021; Mojtaba Lajevardi et al., 2019; Sen et al., 2016; Zhou et al., 2017). Although numerous studies focused on calculating projections and inventories of emissions in different countries caused by the transport sector are in the literature (Alonso et al., 2010; Cifuentes et al., 2021; Das et al., 2021; Fu et al., 2017; Gu et al., 2019; Lv et al., 2019; Mukherjee et al., 2021; Ramachandra and Shwetmala, 2009; Singh et al., 2021, 2017; Zhang et al., 2014, 2013), studies that contemplate the insertion of alternative technologies in the projection of emissions are still scarce. A recent study in the UK takes into account plug-in hybrid vehicles (PHEVs) and battery-powered passenger vehicles to assess the effect of introducing these alternatives on set emission targets (Küfeoğlu and Khah Kok Hong, 2020). This study reflects the difficulty of determining the rate of insertion of these technologies in the future and concludes that with the current pace it would not be possible to meet the proposed objectives, mainly because the ICEVs would move from the market at a lower rate than desired (Küfeoğlu and Khah Kok Hong, 2020).

The estimation of the sector's emissions is necessary to assess the impact of these, the effect of existing regulations, and the need for action to achieve environmental objectives (Singh et al., 2021). The complexity of calculating the emission inventory caused by cargo transport lies mainly in obtaining the necessary information for estimation, the correct segmentation of vehicle types and the correct choice of emission factors (Cifuentes et al., 2021; EEA, 2015). It is for this reason that different levels are established to make the estimate, differentiated by the number of variables needed. The Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2006) proposes a guide based on three levels (Tiers) used by numerous studies (EEA, 2015; Singh et al., 2021). Each Tier represents a level of methodological complexity. Tier 1 involves the basic analysis, using only fuel consumption and their respective emission factors. The use of this methodology is not recommended because of its limited scope, and it is considered mandatory for countries to make efforts to collect the statistical information necessary to use a higher-level methodology. Tier 2 considers a segmentation of vehicles, daily kilometers and different types of fuel. Finally, Tier 3 also includes information about the average speeds of the vehicles. The globally recognized COPERT tool is an example of Tier 3 reach and bottom-up reach, explained below. Some investigations opt for a hybrid version between Tier 2 and Tier 3 (Saija and Romano, 2002).

Once the variables to be used according to the level have been defined, there are two common methodologies for estimating the emissions inventory: bottom-up (BU) and top-down (TD) (Policarpo et al., 2018). The first methodology uses technology-specific emission factors along with annual kilometers driven and the number of vehicles to calculate an annual emissions inventory (Policarpo et al., 2018; Saija and Romano, 2002). This methodology contemplates emissions at the micro level and in an ascending way the information is aggregated to achieve macro levels. Additionally, it is highly recommended by the literature to assess air quality in areas where transportation is the main source of pollution (Pallavidino et al., 2014; Zhang and Chen, 2022) and is the methodology adopted by the United States Environmental Protection Agency (Policarpo et al., 2018). On the other hand, the top-down study uses real data from environmental pollution monitoring or existing national inventories (Abulude, 2021). Then, in the case of cargo transport, the information is disaggregated with data about the resident population, fuel sales, and the length of the roads, among others (Abulude, 2021; Zhang and Chen, 2022). Although the methodologies are complementary and it is even recommended to use both as verification, the scope of the BU is based on a more transparent choice of parameters that implies a more solid estimate (Cifuentes et al., 2021; Pallavidino et al., 2014). In addition, there are other alternatives for the verification of estimates such as estimating emissions from national fuel consumption and verifying with inventories calculated by national institutions, if the country does so (IPCC, 2006; Pallavidino et al., 2014; Zhang and Chen, 2022).

The reliability of the results of the calculations, rather than falling on the chosen methodology, lies in the quality of the data used. Emission factors are one of the most complex parameters to define (Cifuentes et al., 2021; Das et al., 2021). These are obtained through measurements and tests of driving cycles, and depend essentially on fuel quality, vehicle type, age, climatic factors present as well as emission control policies, among others (Abulude, 2021; Das et al., 2021; EEA, 2015; Policarpo et al., 2018). The emission factor is defined as "the mass of pollutant emitted by a vehicle when driving a certain distance, usually expressed in g/km" (Policarpo et al., 2018). There are many estimates of emission factors made by both international institutions and countries. The IPCC (2006) and the European Environment Agency (EEA) (2015) provide the most widely used database of emission factors in international studies when local data are not available. Even a study conducted by the EEA (2015) proves the consistency between both sources of information.

When it comes to pure electric vehicles, CO_2 emissions in the exhaust are zero and, depending on the scope of the analysis, the only emissions to be taken into account are the result of electricity production (EEA, 2015). It is for this reason that in regions where energy generation is mostly based on renewable sources, the incorporation of these vehicles into cargo transport can mean a significant decrease in GHG emissions and other pollutants (Breuer et al., 2021). In addition, the quantification of emissions produced by freight transport is essential to accelerate the implementation of technologies and policies with emission mitigation measures (Ramachandra and Shwetmala, 2009).

In Uruguay, numerous studies have been carried out on the quantification of emissions generated by different sectors. In 1997 the Climate Change Unit (UCC) carried out the first GHG studies and inventories taking 1990 as the base year (Aresti, 2016). Additionally, the National Directorate of Energy (DNE) of the Ministry of Industry, Energy and Mining (MIEM) collects annually in the National Energy Balance the data on total energy consumption of the energy sector and, since 2012, includes CO_2 emissions in Uruguay. Inventories of greenhouse gases (INGEI) emitted and captured by the following sectors are also carried out annually: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Uses (AFOLU) and Waste. The report that quantifies and compiles these results applies the Tier 1 methodology, proposed by the IPCC (2006) and mentioned above, to develop national policies that contribute to decarbonization (Ministerio de Ambiente, 2021). In addition, the top-down analysis is carried out and the disaggregation of information according to vehicle types is proposed as a future improvement.

However, none of the studies mentioned above show the emissions generated specifically by the freight transport sector. Aresti (2016) uses the methodology proposed by the IPCC and the COPERT 4 model to quantify the sector's CO_2, CH_4, and N_2O emissions. Additionally, the Center for Innovation in Industrial Organization (CINOI) carried out along with the Ministry of Transport and Public Works (MTOP) a quantification of the GHG emissions of the sector in 2019. This study also incorporated emission projections with the addition of electric trucks (CINOI, 2019). Finally, similar projections are included in the Long-Term Climate Strategy in Uruguay to achieve CO_2 neutrality by 2050 (Uruguay Presidencia, 2021). This national strategy sets out three main milestones that will mean that, by 2050, 52.1% of the entire national fleet of cargo vehicles, both light and medium and heavy, will be battery or green hydrogen fuel cells. To achieve this, it is intended that by 2035 all new passenger vehicles will be zero-emission, that by 2040 all new light-duty vehicles will be zero-emission, and, finally, that by 2045 all new cargo vehicles will be zero-emission.

Studies related to electric vehicles in Latin America started to appear in the literature in 2001 and have been increasing since then (Ramírez et al., 2021). However, the average share of Latin American literature on electric vehicle knowledge in the global context is low, only 1.8%, and the countries that are leading research in this area are Brazil, México, Colombia and Chile (Ramírez et al., 2021). A recent study carried out in Chile and Colombia compares the well-to-wheel emissions with abatement strategies for passenger vehicles considering different pollutants and greenhouse gases (Cuéllar et al., 2022). This investigation considered three strategies: implementing cleaner vehicles technologies like EURO IV, V and VI, using compressed natural gas (CNG) and using battery electric vehicles. The results show that using fossil fuels does not lead to significant emissions reductions and that while the most efficient scenario is adopting BEVs, the reductions rely strongly on the energy mix used. The adoption of zero emissions technologies in emerging markets and developing economies has been slow-paced and when it comes to medium and heavy duty trucks, the sales in 2020 have been from 1 to 31 electric trucks in LATAM, considering Brazil, Colombia, Ecuador, and Uruguay (ICCT, 2022b).

The studies stated in the Latin American context, along with the existing literature on the adoption of electric vehicles in other regions, shows the potential of this technology in reducing emissions that are harmful to the environment and evidences the importance of accounting for the impacts derived from the adoption of BEVs, especially in the freight transport sector.

3 Methodology

First, greenhouse gases (GHGs) can be divided into two groups. On the one hand, there are direct gases that contribute to the greenhouse effect as they are emitted into the atmosphere. These gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs). On the other hand, there are the precursor gases of tropospheric ozone that in addition to polluting the atmosphere become direct greenhouse gases and are: carbon monoxide (CO), organic compounds other than methane (COVDM), nitrogen oxides (NO_x, which include NO and NO_2) and sulphur dioxide (SO_2). This study includes, within the direct GHGs, CO_2, N_2O, and CH_4 because these gases are the most significant in terms of the contribution to global warming (Dijkstra et al., 2012). NO_x and CO are also considered the precursor gases of tropospheric ozone due to the relevance of these pollutants in the advances of the Euro regulations. In addition, these pollutants are associated with the emission of N_2O as the catalytic converters of vehicles become more efficient in reducing CO and NO_x, due to the oxidation of these (Clairotte et al., 2020). These oxidations cause NO to react with the nitrogen present on the surface of the catalyst and N_2O to form (Clairotte et al., 2020).

The methodologies proposed by IPCC (2006) and EEA (2015) for the calculation of emissions of these gases are widely recognized and applied by international institutions and countries. Two methodologies will be used depending on the information required and the nature of the emissions to be calculated. On the one hand, emissions can be estimated from the fuel consumed, which can be taken as the fuel sold, and, on the other hand, emissions can be calculated from the distance traveled by the vehicles (IPCC, 2006). In general, because CO_2 emissions depend mainly on the carbon content of the fuel, the first calculation method is used. As for the emissions of CH_4, N_2O, CO, and NO_x, these vary depending on several factors, such as emission regulations and gross weight classification, and it is for this reason that the second method presented is commonly used.

As mentioned in the previous section, there are several scopes for performing these calculations, defined by the quantity and quality of data available. In this study, the calculation of CO_2 emissions was performed with a Tier 1, since no country-specific data for carbon contents of the fuel sold is available in Uruguay. The calculation of N_2O, CH_4, CO, and NO_x emissions was performed with a Tier 2 approach, considering that vehicle segmentation data was available. On the other hand, the information available to carry out this study allowed the use of a bottom-up analysis. For both cases it was necessary to know the national fleet of trucks and their respective categories based on the gross combined weight (GCWR).

Finally, to verify the CO_2 calculation methodology, the CO_2 emissions calculated were transformed into energy and compared to the diesel consumption values in the corresponding years. The variation of energy consumption was then calculated to validate the methodology used. The annual diesel consumption by the transport sector was provided by the BEN (MIEM, 2020).

3.1 National fleet and vehicle segmentation

To determine the trucks present in the Uruguayan fleet, several sources were used. On the one hand, a database of trucks registered until 2014 in Uruguay, compiled by the Uruguayan Society of Automotive Technical Control (SUCTA), was used. This records the truck model, year of manufacture, GCWR, and the kilometers traveled by that truck in the years 2013 and 2014. This database was updated with SUCTA data from 2017 and with 2021 data from APPLUS, SUCTA's successor. The final database includes the trucks currently licensed to circulate in Uruguay, their models, their year of manufacture and their GCWR. In addition, the values for each category of the average annual kilometers traveled in 2014 were used for 2021, given that 2014 was the last year in which this specific data was reported.

To present the accumulated data obtained, the segmentation of vehicles according to the ranges of weights used was proposed by EEA (2015) in the Air Pollutant Emission Inventory Guidebook 2016. These cumulative data are shown in Table 1.

Table 1: Cumulative data of national truck fleet

GCWR	Regulations	Quantity	Average km
≤7.5	Prior	240	67.125
	Euro 1	15	112.639
	Euro 2	1.112	40.191
	Euro 3	3. 235	49.247
	Euro 4	466	26.417
	Euro 5	2	59.124
	Total	5.070	
(7.5 – 16]	Prior	177	129.828
	Euro 1	24	130.469
	Euro 2	661	50.890
	Euro 3	3.747	53.505
	Euro 4	69	27.314
	Euro 5	172	78.401
	Total	4.850	
	Prior	2.767	85.724

(16 – 32]	Euro 1	787	59.262
	Euro 2	259	56.869
	Euro 3	1.277	56.211
	Euro 4	0	0
	Euro 5	342	72.760
	Total	5.432	
>32	Prior	2.593	92.760
	Euro 1	1.566	79.895
	Euro 2	1.802	77.701
	Euro 3	12.526	92.457
	Euro 4	133	55.880
	Euro 5	1.058	86.899
	Total	19.678	

Figure 1 shows the segmentation according to the Euro category. It is noteworthy that more than half of Uruguayan trucks are Euro III, and 34% do not reach even this category. Only 7% of trucks exceed Euro III. This situation is mainly because, according to a decree since 2008 it is not allowed to acquire new trucks that do not comply with Euro 3 regulations.

On the other hand, Figure 2 adds weight classification into the Uruguayan truck fleet. This figure shows a predominance of vehicles with Euro 3 regulation for each weight category, except for the category between sixteen and thirty-two tons, where the pre-euro classification still predominates. Note also that the Euro 1 classification still has a considerable presence in this category and in the category above thirty-two tons, while in the smaller weights, the presence of Euro 1 is insignificant and that of Euro 2 begins to take on more relevance.

Figure 1: Segmentation of Uruguayan truck fleet according to Euro regulations

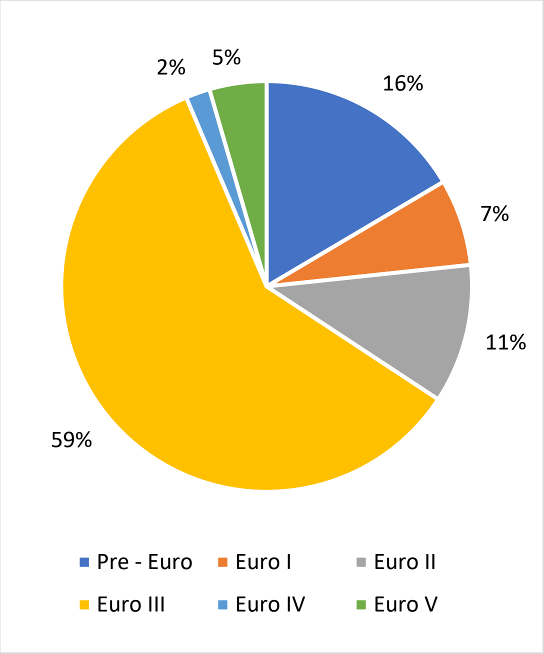
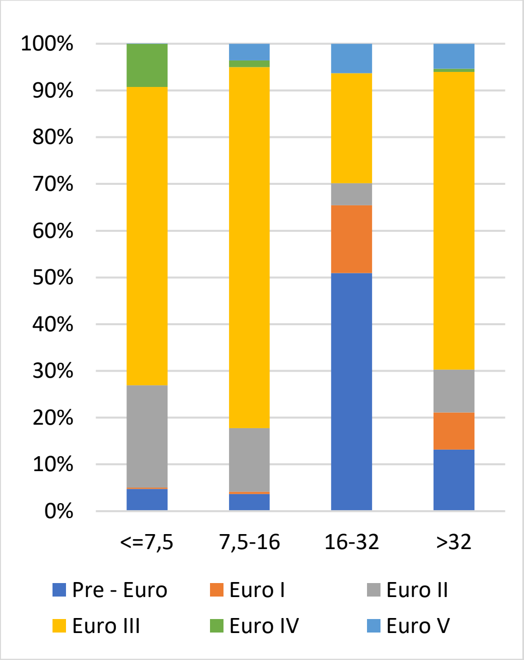


Figure 2: Segmentation of Uruguayan truck fleet by total gross weight and Euro regulations



3.2 Calculation of CO_2 emissions

The estimation of CO_2 emissions is commonly calculated based on the fuel consumed and its carbon content (IPCC, 2006). For this calculation, the IPCC (2006) proposes two different scopes. First, Tier 1 proposes to calculate CO_2 emissions by multiplying the fuel sold with a CO_2 emission factor from literature. On the other hand, the scope of Tier 2 uses the same methodology except that the emission factor used corresponds to the specific region or country where it is located.

Because in Uruguay there are no calculations of emission factors adapted to national conditions (Proyecto MOVÉS, 2021), it was decided to use the scope of Tier 1 proposed by the IPCC (2006) and CO_2 emissions were found according to Equation 1.

Equation 1: Calculation of CO_2 emissions

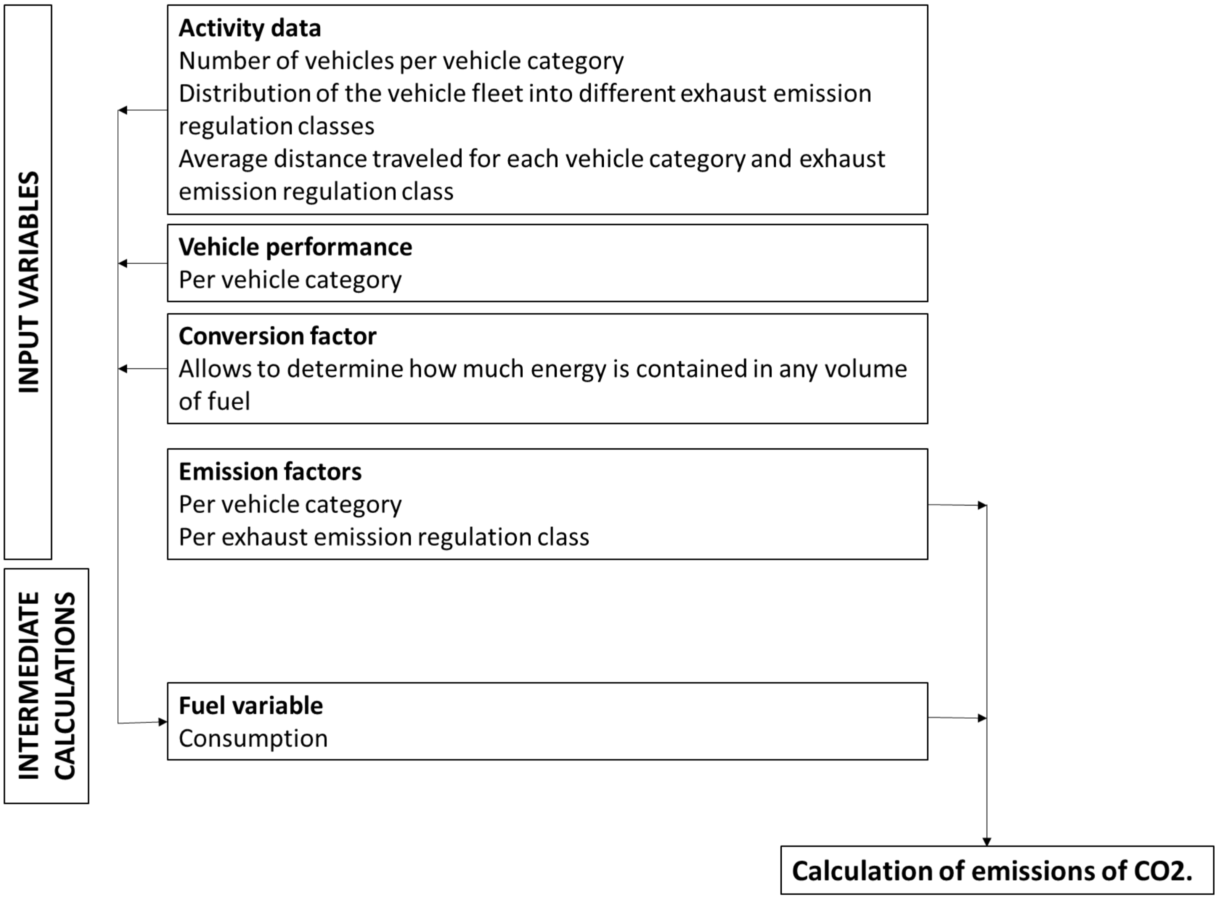
$$Emissions = \sum_{a} (Fuel_a * EF_a)$$

In which:

- Emissions= CO_2 emissions (kg)
- Fuel = fuel consumed (TJ)
- EF = fuel emission factor (kg/TJ)
- a = fuel type a (e.g., diesel, gasoline, natural gas)

In this study, the only fuel considered is diesel, since it is the fuel used by almost every truck in Uruguay. Therefore, the sum results in a single term. Obtaining the amount of fuel consumed was found by the total distance traveled by the vehicles. Considering the baseline input variables needed to reach Equation 1, Figure 3 shows the framework used for these calculations. This framework uses input variables such as activity data, vehicle performance and conversion factors to calculate fuel consumption. This value is then used with the emission factors to calculate CO_2 emissions.

Figure 3: Framework of the variables used in order to reach Equation 1



The new calculation structure can be seen in Equation 2 and then the factors involved, and the methodology used to find them are detailed.

Equation 2: Calculation of CO_2 emissions with development of fuel consumed

$$Emissions\ (kg) = \sum\nolimits_{ij} \frac{K_{ij}(km) * C\left(\frac{tep}{m^3}\right)}{P_i\left(\frac{km}{l}\right) * 1000\left(\frac{l}{m^3}\right) * 1000\left(\frac{tep}{ktep}\right)} * EF\left(\frac{kg}{TJ}\right) * 41{,}868\left(\frac{TJ}{ktep}\right)$$

In which:

- Emissions = CO_2 emissions (kg)
- K = total average annual distance traveled by category i vehicles with regulation j (km)
- C = conversion factor (tep/m3)
- P = performance of category i vehicles (km/l)
- EF= emission factor (kg/TJ)

On the one hand, the average annual distances traveled (Kij) by vehicles of each category and regulations were detailed in the previous section.The conversion factor (C) defines the energy contained in a volume of energy and uses 0.7890 toe/m3, a value found in the BEN (Proyecto MOVÉS, 2021). For the performance of the trucks in each category, a study previously conducted by Tanco (2019) was used. In this study, truck categories are considered and the performance for urban, suburban, and long-distance distribution conditions are based on the literature. For this analysis, the average performance for each operating condition considers a 50% load, which is the national average load for trips (Tanco et al., 2019b). The values used are found in Table 2. Regarding the emission factor used for diesel, the value of 74,100 (kg/TJ) obtained from the IPCC (2006) emission factor database was used because this data does not exist for the country.

Table 2: Average yields by category

Category	Performance (km/l)
≤7.5 tons	6.20
7.5 – 16 tons	4.35
16 – 32 tons	2.49
> 32 tons	2.49

3.3 CO_2 calculation validation

EEA (2015) recommends calculating a fuel balance to corroborate that all fuel used has been considered in emissions calculations. As it was mentioned before, the CO_2 emissions calculated were transformed into energy and compared to the consumption values that were recorded in the corresponding years.

Equation 3 presents the energy consumed by the freight sector, based on the calculation of emissions in the previous section.

Equation 3: Calculation of energy consumed by the transport sector

$$Theoretical\ energy\ (ktep) = \frac{CO_2\ emissions(kg)}{EF\left(\frac{kg}{TJ}\right) * \ 41{,}868\left(\frac{TJ}{ktep}\right) * \%_{diesel\ intended\ for\ street\ transport}}$$

In which:

- Theoretical energy = Energy consumed by the trucks according to emission calculations previously made in ktoe
- CO_2 emissions = Emissions calculated using the methodology explained in Chapter 3.2 in kg of CO_2
- EF = diesel fuel emission factor (kg/TJ) = 74,100 (kg/TJ) (IPCC, 2006)
- % diesel intended for street transport = 99% (MIEM, 2020)

To make the validation, the calculated energy of is compared with the energy consumed by the transport sector as reported (MIEM, 2020). The methodology for calculating the variation between these two values is presented in Equation 4.

Equation 4: Calculation of the variation between energy consumed by the theoretical and real transport sector

$$Variation\ (\%) = \frac{Theoretical\ energy\ (ktep) - Real\ energy(ktep)}{Theoretical\ energy(ktep)} * 100$$

3.4 Calculation of N_2O, CH_4, CO, and NO_x emissions

The emissions of N_2O, CH_4, CO, and NO_x depend closely on the combustion technology and emission control present in the vehicles (IPCC, 2006) differentiated in this study according to the different Euro regulations. It is for this reason that both the methodology for calculating these emissions proposed by IPCC and the one proposed by EEA suggest using larger tiers, preferably Tier 2 and Tier 3.

On the one hand, Tier 2 takes into account the fuel used by each class of vehicles according to Euro standards and their respective emission standards (EEA, 2015). On the other hand, Tier 3 makes a differentiation between two types of emissions: those that occur when it is operating under normal conditions and those emissions during the transient operation of the engine, which is the phase through which the engine passes from start-up until it reaches its normal operating temperature causing higher amounts of emissions (EEA, 2015). For this study, we chose to use Tier 2 due to the availability of information.

Figure 4 shows the framework used for input variables used to calculate emissions of N_2O, CH_4, CO, and NO_x. The activity data variables are segmented by vehicle category and exhaust emission regulation. The average distance travelled for each category is then used for each corresponding emission factor to calculate emissions

Figure 4: Framework of the variables used to reach Equation 5

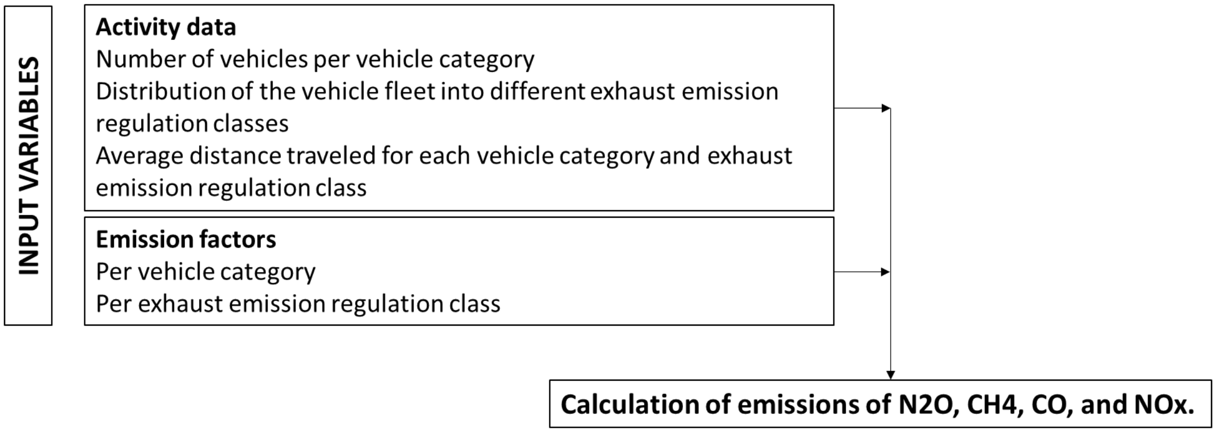


Figure 4 shows the method of calculating the emissions of N_2O, CH_4, CO, and NO_x.

Equation 5: Calculation of emissions of N_2O, CH4, CO and NO_x

$$Emissions_i = \sum_{j,k} N_{j,k} * M_{j,k} * EF_{i,j,k}$$

In which:

- Emissions = emissions of the pollutant i
- Nj,k= number of vehicles of category j and regulation k
- Mj,k = average distance traveled by vehicles of category j and regulation k (km)
- EFi,j,k = pollutant emission factors i for vehicle category j and regulation k (g/km)

The emission factors of the gases were extracted from EEA (2015) and are shown in Table 3. On the one hand, the emission factors of N_2O, CO, and NO_x were directly extracted according to vehicle category and regulations. In the case of NO_x emission factors, these are expressed in NO_2 equivalent. On the other hand, the emission factors of CH_4 are provided according to the type of operation and the total gross weight. For the category of vehicles with a total gross weight of fewer than 7,5 tonnes, the emission factors provided by EEA (2015) are distinguished between normal and transient operating emission factors. For this category, a type of urban transport was assumed and an average of the two factors mentioned was made. For the other categories of vehicles, the emission factors proposed by EEA (2015), which correspond to road transport, were used. A summary of the emission factors used can be found in Table 3.

Table 3: Emission factors used

Category	Regulations	N_2O (g/km)	CH_4 (g/km)	CO (g/km)	NO_x (g/km)
≤7.5 tons	Prior	0,029	0,025	1,85	4,70
	Euro I	0,005	0,0145	0,66	3,37
	Euro II	0,004	0,0065	0,54	3,49
	Euro III	0,003	0,003	0,58	2,63
	Euro IV	0,006	0,0011	0,047	1,64
	Euro V	0,017	0,0000075	0,047	0,93
7.5 – 16 tons inc.	Prior	0,029	0,02	2.13	8.92
	Euro I	0,008	0,02	1.02	5.31
	Euro II	0,008	0,02	0.90	5.50
	Euro III	0,004	0,02	0.97	4.30
	Euro IV	0,012	0,02	0.071	2.65
	Euro V	0,034	0,07	0.071	1.51
16 – 32 ton inc.	Prior	0,029	0,07	1.93	10.7
	Euro I	0,008	0,07	1,55	7.52
	Euro II	0,007	0,07	1,38	7.91
	Euro III	0,004	0,07	1.49	6.27
	Euro IV	0,012	0,07	0.11	3.83
	Euro V	0,034	0,07	0.11	2.18
> 32 tons	Prior	0,029	0,07	2,25	12.8
	Euro I	0,012	0,07	1,90	9.04
	Euro II	0,012	0,07	1,69	9.36

	Euro III	0,007	0,07	1,79	7.43
	Euro IV	0,018	0,07	1,12	4.61
	Euro V	0,053	0,07	1,12	2.63

3.5 Calculation of CO_2 equivalent

Carbon dioxide equivalent ($CO_{2\text{-eq}}$) is a term used to account for different greenhouse gases in a common unit. For a given amount of GHG, $CO_{2\text{-eq}}$ refers to the amount of CO_2 that would have an equivalent global warming impact (Brander, 2012). To find the $CO_{2\text{-eq}}$ of a gas, its "Global Warming Potential" (GWP) index is used, which indicates the amount of global warming it causes in a given period compared to CO_2 (Brander, 2012).

Equation 6 shows the calculation of $CO_{2\text{-eq}}$ considering different GHGs and

Table 4 shows the GWP of the gases in question.

Equation 6: Calculation of carbon dioxide equivalent

$$\mathrm{CO_2-eq} = \sum_i M_i * GWP_i$$

Where:

- $CO_{2\text{-eq}}$ = Carbon dioxide equivalent
- Mi= greenhouse gas mass i
- GWPi= global warming potential of greenhouse gas i

Table 4: Global warming potential of greenhouse gases

Greenhouse gas	Global Warming Potential (GWP)
CO_2	1

N_2O	298
CH_4	25

4 Calculation of emissions

Using the criteria and procedures explained above, Table 5 shows the calculation of the GHG inventory for the years 2014, 2016, 2018, and 2021, using the national fleet data corresponding to each year (APPLUS, 2021). The advantage of having historical data, and records allows the analysis and impact on the variability of the data. In addition, this table shows the average annual increase considering the period 2014-2021.

Table 5: GHG emissions for the years 2014, 2016, 2018, and 2021 and average annual variation

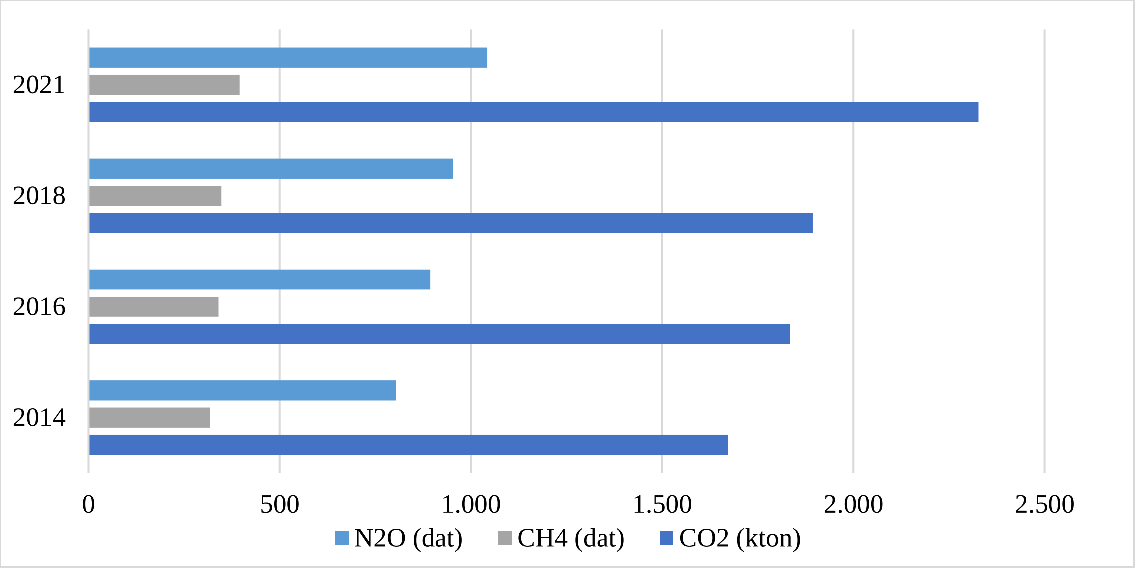
GHG	2014	2016	2018	2021	Average annual increase
CO_2 (ton)	1.671.515	1.834.206	1.894.477	2.327.322	4.84%
CH_4 (ton)	127	136	139	158	3.17%
N_2O (ton)	27	30	32	35	3.78%
$CO_{2\text{-eq}}$ (ton)	1.682.736	1.846.546	1.907.488	2.341.702	4.83%

As for the evolution of these emissions, in the case of CO_2 emissions, an average annual increase of 4.84% can be observed. In the period from 2014 to 2016, the annual increase was 4.75%, followed by an increase of 1.63% per year in the interval from 2016 to 2018. Finally, the range from 2018 to 2021 shows an annual increase of 7.1% in emissions. The significant increase in the last period may be since between 2021 and 2018 5106 units of trucks entered the country while, in the previous periods, this figure was 2699 between 2014 and 2016 and only 763 between 2016 and 2018.

Concerning CH_4 and N_2O, these had similar average annual increases, of 3.17% and 3.78%, respectively. In the range from 2014 to 2016 the increases were 3.48% and 5.4%, while, in the second interval, the increases were 1.1% and 3.3% respectively. Finally, CH_4 and N_2O emissions showed an annual increase of 4.36% and 3.03% in the third interval studied. These increases may be affected by the implementation of new emission control technologies in new vehicle additions since 2008, which are beginning to gain relevance while previous vehicles are becoming obsolete. The current regulation in Uruguay prohibits the entry into the country of any type of vehicle with emission technology lower than Euro III. This standard is expected to change with Decree 135/021 (Lacalle Pou et al., 2021), which indicates that from 2023 only vehicles with Euro V emission technology or higher will be allowed to enter. As mentioned in the previous section (3), as vehicles adopt more stringent Euro regulations, the greater the emission restrictions of ozone precursor pollutants. By oxidizing these contaminants in catalytic converters, they increase the emissions of N_2O emissions from chemical reactions that take place on the surface of the instrument. It is for this reason that it is expected that the emissions of these gases will increase, and it becomes necessary to consider in the analysis of the emissions of NO_x and CO.

On the other hand, the $CO_{2\text{-eq}}$ inventory for the periods analyzed shows the low influence of N_2O and CH_4 emissions compared to CO_2 emissions. This can be seen graphically in Figure 5, which shows the evolution of emissions for the years studied. It should be noted that to be able to compare emissions, CO_2 emissions in kilotons are shown while N_2O and CH_4 emissions are shown in decatons (dat), which equal 10 tonnes.

Figure 5: Evolution of emissions for the years 2014, 2016, 2018 and 2021



Finally, as mentioned in the previous section, the calculations of CO_2 emissions can be validated by looking at the energy consumption due to cargo transport in the corresponding years. Energy consumption is presented annually in the report of the National Energy Balance (Dirección Nacional de Energía, 2020), which also specifies the percentage of diesel consumed dedicated to road transport. Table 6 contains the variation of the emission calculations transformed into energy compared to the recorded consumption values. The variation corresponding to the year 2021 was not found because it is not yet available in this year's National Energy Balance.

Table 6: Variation in emissions calculated against the consumption recorded in the BEN

	2014	**2016**	**2018**	**2021**
Variation	-8,9%	0.83%	3,2%	-

As can be seen, the variations in between the energy consumption reported by the National Energy Balance of Uruguay and the emissions calculated transforming them into energy for the three years are small. 2014 presents the major variation meanwhile in 2016 and 2018 the variations are lower than 5%. This calculation validates the methodology used in this investigation.

5 Future scenarios

Previously, the evolution and current situation of emissions from the freight transport sector was shown, which serves as a starting point for future projections. Currently, the Long-Term Strategy for Low Emissions and Climate Resilient Development is in force, in which Uruguay committed to CO_2 neutrality in 2050. This involves efforts to mitigate and eliminate emissions of this type in all productive sectors. Particularly, in the transport sector, the established strategy is strongly committed to green zero-emission technologies.

To evaluate under which scenarios, it will be possible to comply with the established, three scenarios have been considered. These show the evolution of cargo transport in Uruguay under different criteria for the adoption of technologies and regulations considering the comprehensive economic projections and future policies that will be implemented in the country. The same annual fleet increase rate is considered for each scenario. Given the normal premises established by the MIEM for socio-economic growth (MIEM, 2018) an average annual growth of 1.5% in the number of trucks in circulation is considered.

The first scenario considered corresponds to the Reference Scenario (RS), which describes a future in which transport activity and technological development follow historical trends. As mentioned in the section on vehicle segmentation and national fleet, the Euro III regulation is the one mostly adopted by the sector. In this way, it is considered that heavy transport does not become alternative powertrain technologies, but that vehicle addition complies with Euro III regulations.

Two alternative scenarios were considered that present different positions against the policies to be developed in the future. Each of them is detailed below.

- Established Policy Scenario (EPS): this scenario is central to the energy technology perspectives reports(IEA International Energy Agency, 2021a), which illustrate the effects of current and announced measures. The regulations to be applied in the future are considered, as well as the different levels of incentives programmed by governments. In addition, the expansion plans projected by the manufacturers concerning the available models of electric vehicles are included.
- Sustainable Development Scenario (SDS): this scenario places the perspectives of the IEA based on its publications (IEA International Energy Agency, 2021a). There are three pillars in the Sustainable Development Scenario. These are: ensuring universal access to energy for all by 2030; achieving strong reductions in air pollutant emissions; and meeting global climate goals in line with the Paris Agreement. The Sustainable Development Scenario is based on limiting the increase in global temperature below 1.7-1.8 degrees Celsius with a 66% probability.

In these scenarios, we have on the one hand, the increase in the vehicle fleet and, on the other hand, the replacement of the fleet with electric vehicles. Unlike the RS, both the EPS and SDS consider the incorporation of internal combustion vehicles with Euro V regulations, which is aligned with Uruguayan legislation, which will not allow the entry of trucks with lower standards in 2023. For the replacement of electric vehicles, global stock projections of these vehicles are taken into account (IEA International Energy Agency, 2020b). Table 7 shows the percentage of stock in vehicles with alternative technology for each five-year period until 2050. These stock percentages are averages among all the regions considered by the study (Europe, United States, China, Japan, India, and other regions) and are segmented into two categories: light electric vehicles (LDVs) with a GCWR less than or equal to 7.5 tons and medium-heavy duty electric vehicles (MHDVs), which are above 7.5 tons GCWR. In this way, the percentages presented in the table show the percentage of stock of each segment for each scenario and year. To contemplate these levels of stock of electric vehicles, it is assumed that the replacement is carried out by eliminating the oldest trucks and with Euro minor regulations present in the vehicle fleet. Additionally, when ICEV is replaced by BEV or FCEV, the latter are considered not to emit CO_2, which is a successful approximation because Uruguay has a 95% renewable energy matrix (on average from 2016 to 2021) (MIEM, 2021).

Table 7: Projections for truck stock with alternative technologies in the coming decades for the EPE and EDS scenarios

Scenarios		**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
EPS	**LDV**	3%	8%	16%	24%	32%	40%
	MHDV	0.5%	1%	3%	7%	18%	35%
SDS	**LDV**	5%	14%	19%	30%	40%	50%
	MHDV	1.5%	3%	6%	12%	24%	45%

The light vehicle segment presents a 3% of stock by 2025 in the EPS scenario, while by 2030, this number rises to 8%. For the same year, the SDS scenario projects a stock of 14%, increasing to

19% in 2035, to 30% in 2040, and finally to 50% of the total stock in 2050 (IEA International Energy Agency, 2021a).

As for heavy vehicles, the progressive electrification of the road transport sector by 2030, in both scenarios, is accompanied by the emergence and consolidation of other propulsion technologies supported by governments (IEA International Energy Agency, 2021a). By 2030, the stock of electric trucks covers 1% and 3% of the total stock for each scenario. FCEVs are beginning to make their way, with commercially available FCEV cars and growing sales in long-range segments, and more FCEV truck models are being announced (IEA International Energy Agency, 2021b). However, its market share remains low during the 2030s, reaching 1% of global car sales by 2030 in SDS. With technological learning, FCEV sales are expected to accelerate after 2030. By 2040, the EPS shows a 7% share in electric trucks, while the SDS reaches a 12% share in this segment. Finally, in 2050 great advances are shown in this cargo segment, reaching a representation of 35% of the national vehicle fleet in the most pessimistic scenario (EPE) and 45% in the most optimistic scenario (SDS). Table 8 shows, by way of example, the stock of conventional trucks in the SDS scenario. It is observed that this scenario assumes that all trucks between 7.5 and 32 tons are electric.

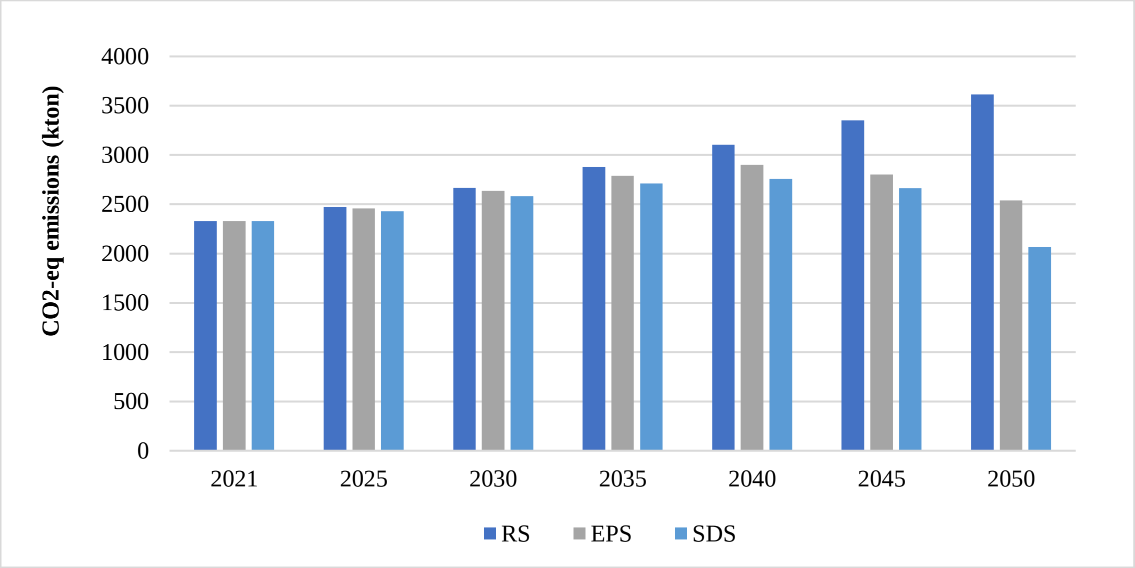
Table 8: National fleet projections in sustainable development scenario (ESD)

Category	**Regulations**	**2021**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
≤7.5 ton	Prior	240	0	0	0	0	0	0
	Euro I	15	0	0	0	0	0	0
	Euro II	1. 112	1. 098	552	173	0	0	1. 112
	Euro III	3. 235	3. 235	3. 235	3. 235	2. 565	1. 669	387
	Euro IV	466	466	466	466	466	466	466

	Euro V	2	321	752	1. 218	1. 721	2. 264	2. 851
7.5 – 16 ton	Prior	177	18	0	0	0	0	0
	Euro I	24	24	0	0	0	0	0
	Euro II	661	661	458	119	0	0	0
	Euro III	3. 747	3. 747	3. 747	3. 747	3. 004	1. 143	0
	Euro IV	69	69	69	69	69	69	0
	Euro V	172	478	890	1. 335	1. 816	2. 336	0
16 – 32 ton	Prior	2. 767	2. 608	2. 423	2. 024	1. 162	0	0
	Euro I	787	787	787	787	787	88	0
	Euro II	259	259	259	259	259	259	0
	Euro III	1. 277	1. 277	1. 277	1. 277	1. 277	1. 277	0
	Euro IV	0	0	0	0	0	0	0
	Euro V	342	684	1. 146	1. 645	2. 184	2. 766	0
> 32 ton	Prior	2. 593	2. 434	2. 249	1. 850	988	0	0
	Euro I	1. 566	1. 566	1. 566	1. 566	1. 566	693	0
	Euro II	1. 802	1. 802	1. 802	1. 802	1. 802	1. 802	0
	Euro III	12. 526	12. 526	12. 526	12. 526	12. 526	12. 526	10. 764
	Euro IV	133	133	133	133	133	133	133
	Euro V	1. 058	2. 298	3. 971	5. 778	7. 730	9. 838	12. 115

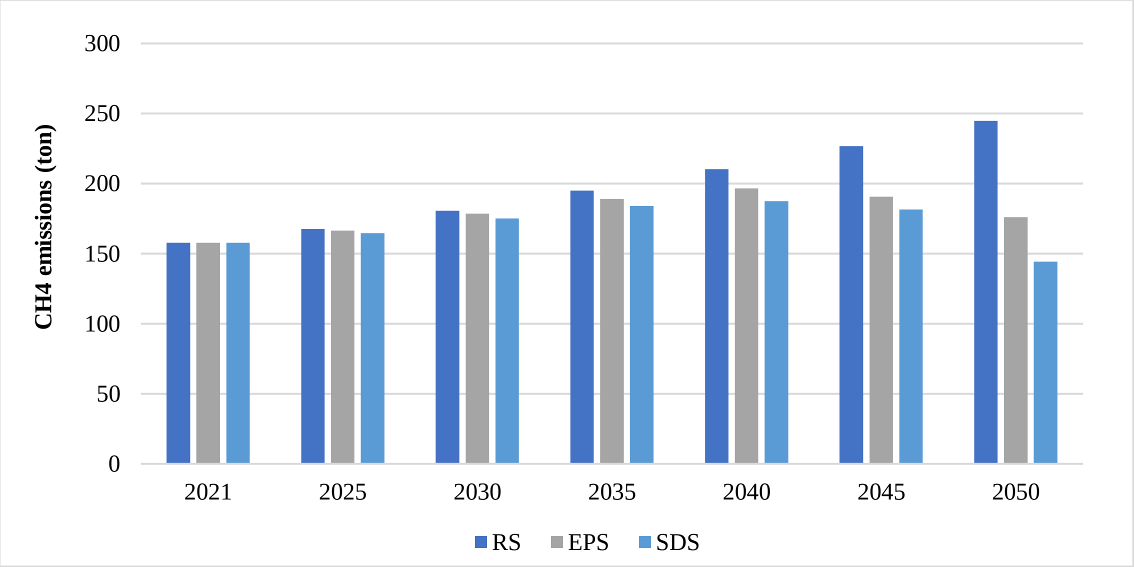
Trends in $CO_{2\text{-eq}}$, N_2O, and CH_4 emissions are then analysed based on the scenarios mentioned above. The reference scenario in Figure 6 shows that from 2021 to 2050, $CO_{2\text{-eq}}$ emissions could increase by 55.3% while in the current policy scenario the increase would be much lower (9.1%). The most favourable case occurs in the scenario of sustainable development, when the incorporation of electric trucks is greater, given that in 2050 emissions would be 11.3% below today's emissions. Additionally, it is observed that 2040 is the year of the breakdown of emissions because they begin to decrease in the two scenarios analysed, even though the national vehicle fleet increases.

Figure 6: $CO_{2\text{-}eq}$ emission projections



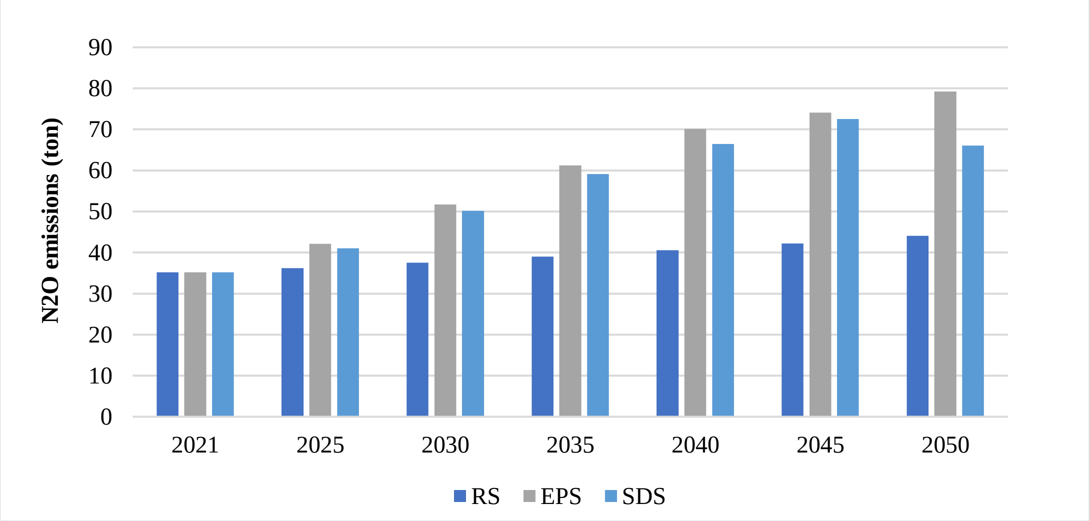
While $CO_{2\text{-}eq}$ accounts for N_2O and CH_4 emissions, calculations of current inventories calculated above show that these have minimal influence. To observe how these emissions, behave through the years analysed and the scenarios presented, Figure 7 and Figure 8 are shown.

Figure 7: CH_4 emission projections



On the one hand, CH_4 emissions behave like $CO_{2\text{-eq}}$ emissions, increasing by 55.1% in the RS, 11.6% in the EPS, and decreasing by 8.6% in the SDS from 2021 to 2050. Like $CO_{2\text{-eq}}$, the year of the breakdown of CH_4 emissions occurs in 2040.

Figure 8: N_2O emission projections



N_2O emissions show a behaviour contrary to the emissions of the two previous gases. With the reference scenario, increases of 25.1% are obtained from 2021 to 2050, which is low compared to the scenario of established policies, where the increase is 125% in that period, approximately. The scenario with the highest insertion of electric vehicles presents an increase in N_2O emissions of 87.6% by 2050. This scenario presents higher N_2O emissions than the RS but is better than the EPS. The fact that the EPS scenario is worse in terms of N_2O emissions compared to SDS is since it has a lower percentage of electric vehicles and, therefore, a higher percentage of vehicles with Euro V regulations. Despite presenting increases, the global effect of global warming because of $CO_{2\text{-eq}}$ emissions from the sector decreases in both scenarios analysed.

Concerning NO_x and CO pollutants, these are reduced by the incorporation of vehicles with Euro V regulations, as shown in Figure 9 and Figure 10. By 2050, the SOE would mean an inventory of NO_x and CO 35.7% and 43.9% lower than in 2021, respectively. The most optimistic scenario, SDS, would reflect in 2050 a decrease of 46.8% and 53.4% of NO_x and CO inventory compared to 2021. When the three scenarios in 2050 are considered, it is observed that there are no very significant differences between the EPS and the SDS. The EPS would mean inventories of NO_x and CO 56.8% and 63.9% lower than the RS, respectively, while with the SDS these values would be 64.2% and 69.9% lower than the RS, respectively.

Figure 9: NO_x emission projections

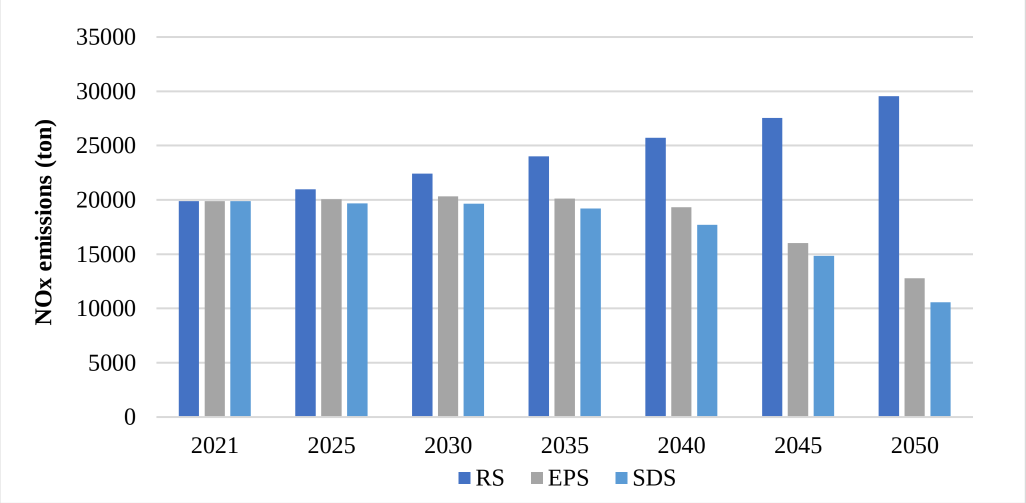
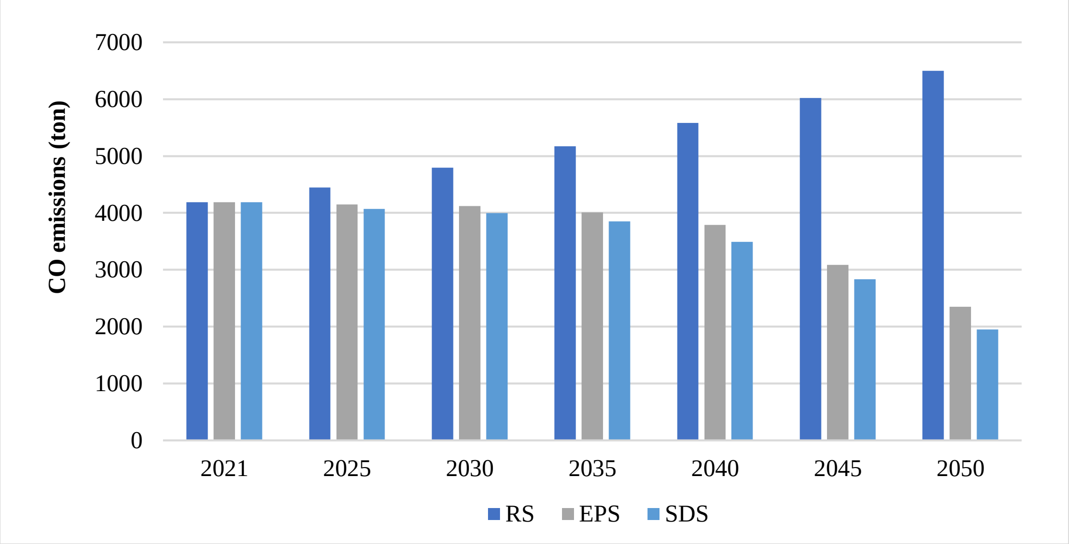


Figure 10: CO emission projections



6 Discussion

As the initial object of the study, the characterization of the vehicle fleet of the road cargo transport sector was obtained. The data obtained from the competent entities made it possible to quantify the trucks in circulation according to their GCWR, their Euro regulations, and the annual kilometers traveled on average. This first characterization made it possible to calculate greenhouse gas emission inventories from 2014 to 2021 rigorously. Among the results obtained in the period analysed, the increase in CO_2 stands out, which was 4.84% per year on average, resulting in approximately 2.327 kilotons in 2021. In addition, CH_4 and N_2O emissions in 2021 demonstrated the low influence of these gases on the calculation of $CO_{2\text{-eq}}$.

The subsequent study of future scenarios evidenced possible decreases in emissions of both greenhouse gases and ozone precursor gases through the application of policies and regulations that restrict them. The scenarios presented contemplate standards for improving Euro regulations at the national level and global standards for the incorporation of electric trucks. These last standards were proposed by the International Energy Agency (2021a) and assume that, by 2050, in the current policy scenario 40% of the world's light truck fleet and 35% of medium and heavy trucks will be electric (battery or fuel cell). The sustainable development scenario projects greater insertion of these technologies, foreseeing that 50% of the inventory of light trucks and 45% of medium and heavy trucks in the world are electric. For this study, these global percentages were reflected for the national fleet, however, the Long-Term Climate Strategy (Uruguay Presidencia, 2021) aims to achieve CO_2 neutrality by 2050, which means more ambitious goals for the cargo transport sector. This national strategy sets out three main milestones in this sector. It is intended that by 2035 all new passenger vehicles will be zero-emission, that by 2040 all new light-duty vehicles will be zero-emission, and, finally, that by 2045 all new cargo vehicles will be zero-emission. These milestones would mean that by 2050 52.1% of the entire national fleet of cargo vehicles, both light and medium and heavy, will be battery or green hydrogen fuel cells. This shows that Uruguay was projected to have higher levels of insertion of electric trucks than the world average. However, it should be borne in mind that the global percentages cover both highly developed regions in terms of electric mobility and regions in which progress is minimal. There are also even more demanding scenarios than that foreseen by Uruguay, such as the one proposed by Yang (2009), who assumes that 79% of the vehicle fleet in California is electric to reduce 80% of CO_2 emissions concerning the inventories of 1990 (Yang et al., 2009). When comparing to the Latin American context, the ambitious goals proposed by Uruguay are supported by Chile, who has set similar milestones: by 2034, all urban busses and light and medium vehicles sold must be zero-emissions and by 2045, all heavy-duty vehicles and intercity busses must also be zero-emissions. Like Uruguay, these goals are supported by the Chilean National Electromobility Strategy, that was published in 2017 (ICCT, 2022a).

Regarding the results obtained from the scenario analysis, it is highlighted that the decreases in emissions concerning 2021 begin to occur from 2040, because of the replacement of old vehicles and with low emission regulations by electric vehicles or with Euro V regulations. In the national strategy mentioned above this inflection point where emissions begin to decrease takes place in 2027 (Uruguay Presidencia, 2021). These figures are another indicator that the scenarios proposed by Uruguay are more demanding than those considered worldwide. On the other hand, in this study, the most favourable scenario corresponds to the sustainable development scenario and supposes in 2050 a $CO_{2\text{-eq}}$ inventory of 2065 kilotons, 42.9% lower than the reference scenario. For its part, the current policy scenario assumes, in the same year, a $CO_{2\text{-eq}}$ inventory of 2540 kilotons, 29.8% lower than the reference scenario. Uruguay projects, within the national strategy, that, due to the existence of sources that absorb CO_2, the entire transport sector should have only 1100 kilotons of $CO_{2\text{-eq}}$ in 2050 to reach neutrality. These values demonstrate that if Uruguay follows the global trends that are projected in 2021, even with the most optimistic scenario it would not achieve the objectives of neutrality in 2050. The main cause of this result is that even in 2050 there would be additions of vehicles with fossil fuels. Logan and Nelson (Logan et al., 2021) argue that, if emissions targets were to be achieved in the UK, the sale of internal combustion vehicles should be banned from 2035. This position is supported by Güzel and Alp (2020), which proposes a scenario of a ban on diesel vehicles from 2030, reducing emissions by 17%.

On the other hand, in addition to $CO_{2\text{-eq}}$ emissions, an indicator of Uruguay's contribution to climate change mitigation is the decrease in ozone precursor gases. For this reason, the evolution of NO_x and CO emissions were analysed in the scenarios mentioned above. Both gases decrease significantly in the two scenarios mainly due to the double effect that is considered when replacing conventional trucks with electric or trucks with Euro V regulations. The inflection points at which emissions begin to decline is for both gases in 2030, ten years before the $CO_{2\text{-eq}}$ inflection point. This difference is due to the influence that Euro regulations have on the emissions of these gases.

If the point of view of manufacturers and suppliers is considered, the application of standards provides them with a possibility to plan for the long term and with certainties regarding their investments (Earl et al., 2018), but delays high market insertion scenarios (Trencher et al., 2020). The manufacture of BEVs and FCEVs is faced with many challenges in terms of technological advances and, as they still cannot benefit from economies of scale, manufacturing costs are still elevated. When it comes to BEVs, vehicles with low load capacity and shorter ranges may be the most efficient market segment for their introduction. On the other hand, FCEVs, presenting higher costs and load capacities, can be focused on large companies or organizations with more demanding needs (Trencher et al., 2020).

Another challenge to consider that the insertion of these technologies can decrease is the preparation that countries can present in the face of this wave of electric vehicles through the installed infrastructure. Government measures should accompany these complementary factors to alternative technologies, either by installing chargers in different parts of the country or establishing a sustainable source of hydrogen (Trencher et al., 2020). In addition to the stability of the hydrogen source, consumers may have concerns about the emissions associated with these sources.

The deadlines needed to change the transport system are long. An important short-term focus is to identify mitigation strategies in key subsectors, including attempts to bring highly efficient alternative fuel vehicles to market. Some alternatives for improving efficiency in the sector are presented by Tanco (2019). The options presented include those that reduce fuel consumption and, therefore, GHG emissions and ozone precursor gases such as the incorporation of elements that improve the aerodynamics of the vehicle, the use of additives and lubricants, and efficient handling, among others. It may also be beneficial in the short term to increase funding and policy support for transport research, considering vehicle technologies and fuels, urban planning, and transport demand management strategy.

7 Conclusions

Finally, this study shows a reliable approach to the calculation and estimation of CO_2 emissions in Latin America according to scenarios based on global trends in the incorporation of electric trucks. On the one hand, the characterization of the vehicle fleet of the road cargo transport sector was obtained, which enabled the calculation of the greenhouse gas emission inventories from 2014 to

2021. On the other hand, the study of future scenarios enlightened the possibility of both greenhouse gases and ozone precursor gases emissions reductions through the application of policies and regulations that restrict them.

This study is easily replicable for countries in the region and has the value of comparing the progress at the country level with the expected progress of the technologies. In the case of Uruguay, the results demonstrate the country's ambitious goals to combat climate change and the need for greater efforts to meet the established targets. This study can be considered as a starting point to know the specific sectors on which to act and the generation of public policies.

It should be noted that this study is not without limitations. Although the calculations were made with the information currently available and with projections based on this information, a more precise study in the future must consider real data to obtain greater precision in the emission calculations. The uncertainty assessment of the calculation of emissions can rely primarily on the calculation of CO_2, since CO_2 contributes to 97% of CO2-eq (IPCC, 2006). Due to lack of specific emission factors for Uruguay standardized emission factors were used, and these present an uncertainty of around 5%, as stated by the IPPC methodology (IPCC, 2006). Limitations considering the estimation of kilometers driven by each segment based on the kilometers registered in 2014 should also be addressed. Finally, despite the limitations, it is understood that this study is of value to analyse the specific impact of adopting BEVs and FCEVs in the freight transport sector, something that until now had not been considered.

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