Chapter 13
Evaluation of the Reduction Potential of Pollutant Emissions by Implementing the Start-Stop System in the Internal Combustion Vehicle Fleet of the City of São Paulo, Brazil

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Abstract The Brazilian transportation sector accounts for almost half of the carbon dioxide emissions in the country, and more than 90% of these emissions come from ground transportation. In 2017, Brazil had approximately 97 million vehicles, with 7.8 million in the city of São Paulo, the majority of which were powered by internal combustion engines. Due to CO_2 reduction emission goals, many countries have plans to extinguish combustion vehicles by 2040. The start-stop system, a cheaper technology, became a trend in the hybrid vehicle market with the purpose of reducing fuel consumption and thereby reducing pollutant emissions. The São Paulo Traffic Engineering Company (CET) annually publishes the Volume and Speed Report that presents the characteristics of the São Paulo city traffic. The São Paulo State Environment Company (CETESB) publishes annually the Fleet Vehicle Emissions Report and its data. Using these public data, the present work performed a bottom-up analysis to evaluate the reduction potential of pollutant emissions for the city of São Paulo by changing the lightweight vehicle fleet to include start-stop system vehicles. This study obtained a reduction potential factor of total emissions between 12.3% and 13.8%, and a CO_2 emission reduction potential for São Paulo of 1,338,341 annual tons.

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Introduction

Since the industrial revolution, air pollutants have increased yearly. There is evidence that increasing CO_2 concentration in the atmosphere may increase the planet's average temperature, thereby causing climate changes. In 2016, the Brazilian transportation sector accounted for 45.3% of the country's CO_2 emissions. São Paulo State vehicles emitted 40.29 million tons of CO_2 (EPE 2016; CETESB 2017).

Automobiles, trucks and motorcycles usually use internal combustion engines as its driving power; conversion efficiency is restricted by thermodynamic laws, since it converts chemical energy from fossil fuel or biofuel into mechanical energy in an irreversible way (ANFAVEA 2018; Spiro 2009).

In recent years, the automotive industry has undergone many changes due to new technologies available. In 2017, countries such as Germany, France, England and China had set targets for the extinction of internal combustion engines in their fleet by 2040 (Teixeira and Calia 2013; The Economist 2017).

Hybrid-Electric Vehicles (HEV) became an alternative to reduce fuel consumption and pollutant emissions; they avoid losses while the vehicle is stopped by shutting down the engine (Reynol 2007; Wills 2008).

Hybrid vehicles use more than one driving power. The HEV have both a combustion engine and an electric motor. It has several levels of hybridization, varying according to their ability of performance improvements (Bosch 2005; Ehsani et al. 2010).

Plug-in hybrids can connect to the electric grid to recharge its batteries. The off-grid hybrids recharge their batteries exclusively from the combustion engine's alternator, and the lowest level of hybridization is the start-stop system that shuts down the engine when it is not necessary, acting only at the start of the vehicle (Ehsani et al. 2010). However, in cities such as São Paulo, where vehicles remain standstill for long periods of time, such a system has great potential for reducing both fuel consumption and pollutant emissions (Bishop et al. 2007; Fonseca et al. 2011).

The start-stop system is activated when the vehicle is at standstill, the driver has the foot on the brake and does not the press clutch or accelerator, the car is in neutral gear, and the battery level may be enough to turn on the engine. The engine is turned down, being ready to restart in approximately 350 μs. Once the engine is turned down, the emissions and fuel consumption are ceased too, which allows one to infer that each stopping situation offers an opportunity to reduce emissions, since burning fuel during stops does not provide power to move the vehicle (Verzimiassi 2012).

Several manufacturers have already adopted the start-stop system by installing a button in the vehicles that allows for easy activation. In Brazil, brands such as Fiat, Renault, Chevrolet and Volkswagen have classic lines equipped with the start-stop system. In addition, the implementation of this system in non-hybrid vehicles is possible.

Some authors found increases in the overall vehicle efficiency of around 15% along with a reduction in CO_2 emissions. Other studies showed that this technology is capable of reducing only 2% of fuel consumption. Considerations of each author varied considerably, such as the period of time the vehicle remained stationary, making the comparison difficult (Bosch 2005; Ehsani et al. 2010; Melo et al. 2018).

Energy consumption and CO_2 emissions are directly connected because the energy sector is based on fossil fuels. Road transportation is the largest energy consumer in the transport sector, amounting to 93.7% of total energy consumption.

Several countries have adopted measures to reduce greenhouse gas emissions (GEE). The Copenhagen Accord, signed in 2009, established targets for reducing GEE between 5% and 45% by 2020 in several signatory countries. In Brazil, Law 12,187/2009 sets a reduction between 36.1% and 38.9% by the year 2020 (EPE 2016; Wills 2008; Vonbun 2017; Brasil 2009).

According to November, 2017 data from the Brazilian National Transit Department (DENATRAN), of the 96,790,495 vehicles in Brazil, 52,769,600 were automobiles, 2,716,258 trucks and 21,548,767 motorcycles. In addition, 47.14 million vehicles of the Brazilian fleet were located in the southeast region, 7,805,127 in the city of São Paulo, with 5,442,775 being automobiles (IBGE 2017; DENATRAN 2017).

The mobility of public roads in São Paulo is reported annually by the São Paulo Traffic Engineering Company (CET) in a report called the São Paulo Main Roads Mobility (MSVP). It presents average speeds, average delay time and traffic volume in segments of each main street. The 2016 report issued in July, 2017 with on-site data collection according to Board 13.1 methodologies, indicated an average delay (percentage of travel time with vehicle stopped) of 25% between 7 a.m. and 10 a.m., and 31% between 5 p.m. and 8 p.m. (CET 2017).

Based on the above scenario, this work aimed to evaluate the potential for reducing emissions of air pollutants by analyzing the modification of São Paulo's internal combustion fleet to vehicles equipped with the start-stop system.

Board 13.1 MSVP 2016 measurement methodology

Measurement	MSVP 2016—measurement methodology
Travel time	Global Position System (GPS) (latitude, longitude, every second) Route maps and GPS points reads in QGIS and Mapinfo
Total delay	Stops deducted from GPS points (grouping of points - speeds up to 4 km/h)
Traffic light delay	Stopped time duration records (with stopwatch) and stopped time (according to the GPS clock)
Traffic delay	Calculated by the difference between the total delay and the traffic light delay

Source Author

Methodology

The potential for reducing the atmospheric emissions of personal vehicles in the city of São Paulo was estimated from public databases and reports. The atmospheric pollutants included in the analysis were carbon monoxide (CO), non-methane hydrocarbons (NMHC), methane (CH_4), nitrogen oxides (NO_x), aldehydes (RCHO), particulate matter (PM), carbon dioxide (CO_2) and nitrous oxide (N_2O). Calculations of annual pollutant emissions were carried out on the current fleet of São Paulo, based on the same calculation done by the São Paulo State Environment Company (CETESB). The emission of pollutants from the same fleet in periods of shutdown based on the CET 2016 MSVP report (CET 2017) was also estimated, which informs the average retardation percentage (mean time in which vehicles remain stopped at intersections or congestions of the total time in transit) in the city of São Paulo.

Databases

Information was used from available databases of the CETESB for light-duty vehicles fueled by gasoline or ethanol and three types of engines: gasoline, ethanol and flex-fuel. Therefore, pickups, vans, motorcycles and heavy vehicles were not considered. The databases use weighted average values, which made it possible to calculate values without needing to distribute the power ranges of vehicles. It also presents the current phase of the Air Pollution Control Program for Automotive Vehicles (PROCONVE) and serves as a reference of maximum permitted emission values.

Emission Factor

The 2016 database presents information on how much a vehicle emits per type of pollutant per kilometer as defined in NBR 6601 ABNT (2012), conducting the test controlling temperature, atmospheric pressure and humidity, and using the driving cycle Federal Test Procedure 75. The data is segmented by year and type of fuel used. The values for vehicles named Gasoline/Gasoline type C and Flex-Gasoline/Flex-Gasol.C all consider the mixture of 78% of gasoline and 22% of anhydrous ethanol as standard fuel, according to Law 10,203 (Brasil 2001); the names differ because of the fuel for which the vehicle was designed. Gasoline type C is regulated by Law 13,033 (Brasil 2014), which establishes the mixture of 72.5% of gasoline and 27.5% of anhydrous ethanol. Vehicles named flex-ethanol refer to flex-fuel vehicles using hydrated ethanol as fuel; however, given the lack of information regarding the use of hydrated ethanol compared to gasoline, all flex-fuel vehicles in this analysis were considered using Gasoline type C.

Table 13.1 shows the pollutant's emission factors for the years 2015 and 2016 per year of manufacture and type of vehicle. It also presents the PROCONVE phase,

Table 13.1 Emission factors for new lightweight vehicles

Year	Fuel	PROCONVE Phase	CO (g/km)	NMHC (g/km)	CH_4 (g/km)	NO_X (g/km)	RCHO (g/km)	PM (g/km)	CO_2 (g/km)	N_2O (g/km)	Vehicle Range (km/l)
2015	Gasoline	L6	0.171	0.012	0.005	0.022	0.0015	0.001	187	0.020	11.7
2015	Flex-Gasoline	L6	0.221	0.017	0.004	0.015	0.0013	0.001	167	0.018	13.2
2015	Flex-Ethanol	L6	0.357	0.055	0.025	0.016	0.0076	ND	157	0.017	9.3
2016	Gasoline	L6	0.244	0.015	0.004	0.013	0.0011	0.001	162	0.020	13.6
2016	Flex-Gasoline	L6	0.249	0.018	0.003	0.013	0.0009	0.001	159	0.018	13.8
2016	Flex-Ethanol	L6	0.363	0.049	0.028	0.013	0.0065	ND	151	0.017	9.7

ND data not available
Source CETESB (2017)

Table 13.2 Active lightweight fleet in the city of São Paulo in quantity and type of fuel

Manufacturing year	Vehicles (Gasoline)	Vehicles (Ethanol)	Vehicles (Flex-fuel)
2016	15,178.8	0.0	151,556.1
2015	25,149.8	0.0	187,366.0
2014	16,915.1	0.0	209,672.8
2013	18,671.5	0.0	229,655.6
2012	23,548.9	0.0	230,669.8
2011	33,042.4	0.0	211,868.4
2010	20,420.5	0.0	221,646.5

Source CETESB (2017)

which is the autonomy in kilometers per liter of fuel. The database presents the annual average between 1982 and 2016. The L6 phase of PROCONVE began in 2014 and is the sixth stage focused on light vehicles.

Active Fleet in São Paulo State

The information presented is related to the vehicles that transit in several cities of the São Paulo State. The data was separated by type of vehicle, volume of vehicles circulating for each manufacturing year between 1976 and 2016 and volume for each city in the São Paulo State.

Table 13.2 presents the active fleet in the city of São Paulo, considering only light vehicles, and lists them by production year and type of fuel used for the years 2000 to 2016. Production of vehicles purely fueled by ethanol was discontinued in 2006 through the inclusion of flex-fuel vehicles in the national fleet, which began in 2003.

Use Intensity

The following data shows how much a vehicle travels on average per year. The values presented in 2016 are the same values included in the 2014 and 2015 databases available on the CETESB website (CETESB 2017).

Table 13.3 shows the values in kilometers for each type of fuel and years of vehicle use, between 0 and 40 years. The vehicles are separated annually in three types of fuels: gasoline, ethanol and flex-fuel.

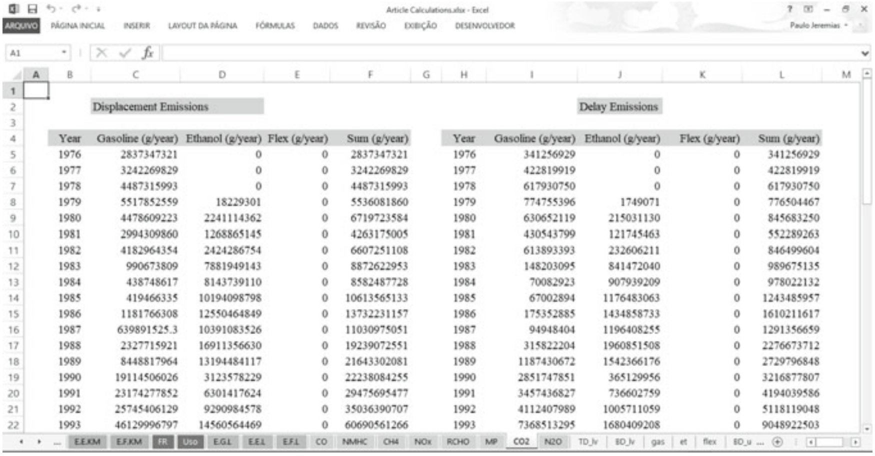
The databases were selected and copied to an excel workbook created by the author. In this workbook, the three databases presented the same structure, separated by the type of fuel used and the manufacture year.

Figure 13.1 shows a screenshot of the worksheets. The sum columns in the visible tab show the calculations for the CO_2 emissions presented in grams of pollutant per year.

Table 13.3 Reference usage intensity

Years of use	Gasoline vehicles (km/year)	Ethanol vehicles (km/year)	Flex-fuel vehicles (km/year)
0	5998	ND	8610
1	11,997	ND	17,220
2	12,632	ND	15,968
3	13,177	ND	15,277
4	13,635	ND	15,001

ND data not available
Source CETESB (2017)



Displacement Emissions

Year	Gasoline (g/year)	Ethanol (g/year)	Flex (g/year)	Sum (g/year)
1976	2837347321	0	0	2837347321
1977	3242269829	0	0	3242269829
1978	4487315993	0	0	4487315993
1979	5517852559	18229301	0	5536081860
1980	4478609223	2241114362	0	6719723584
1981	2994309860	1268865145	0	4263175005
1982	4182964354	2424286754	0	6607251108
1983	990673809	7881949143	0	8872622953
1984	438748617	8143739110	0	8582487728
1985	419466335	10194098798	0	10613565133
1986	1181766308	12550464849	0	13732231157
1987	639891525.3	10391083526	0	11030975051
1988	2327715921	16911356630	0	19239072551
1989	8448817964	13194484117	0	21643302081
1990	19114506026	3123578229	0	22238084255
1991	23174277852	6301417624	0	29475695477
1992	25745406129	9290984578	0	35036390707
1993	46129996797	14560564469	0	60690561266

Delay Emissions

Year	Gasoline (g/year)	Ethanol (g/year)	Flex (g/year)	Sum (g/year)
1976	341256929	0	0	341256929
1977	422819919	0	0	422819919
1978	617930750	0	0	617930750
1979	774755396	1749071	0	776504467
1980	630652119	215031130	0	845683250
1981	430543799	121745463	0	552289263
1982	613893393	232606211	0	846499604
1983	148203095	841472040	0	989675135
1984	70082923	907939209	0	978022132
1985	67002894	1176483063	0	1243485957
1986	175352885	1434858733	0	1610211617
1987	94948404	1196408255	0	1291356659
1988	315822204	1960851508	0	2276673712
1989	1187430672	1542366176	0	2729796848
1990	2851747851	365129956	0	3216877807
1991	3457436827	736602759	0	4194039586
1992	4112407989	1005711059	0	5118119048
1993	7368513295	1680409208	0	9048922503

Fig. 13.1 Print screen of worksheet used for data manipulation. *Source* Author

The road system considered in the 2016 Mobility Report of São Paulo City Main Roads System (CET 2017) had 28 routes chosen in a non-random manner and classified by operational and historical criteria. In operational criteria, the human resources' restrictions make it impossible to perform studies of all the roads at the same period of the year. The system considers both directions, neighborhood to center and center to neighborhood, and covers a total of 220 linear kilometers of roads.

- The Volume and Speed Report (CET 2017) presented average speed and average idle time of the main road system, being the average speed given in kilometers per hour as the average of three samples from the same route at similar times. The average idle time is calculated by dividing the sum of time with vehicle stopped by the total time of the route traveled, considering stopped when the GPS points collected were very close to each other with an average speed between points less than 4 km/h.

Figure 13.2 presented the speed tree and the stratified idle tree for each period

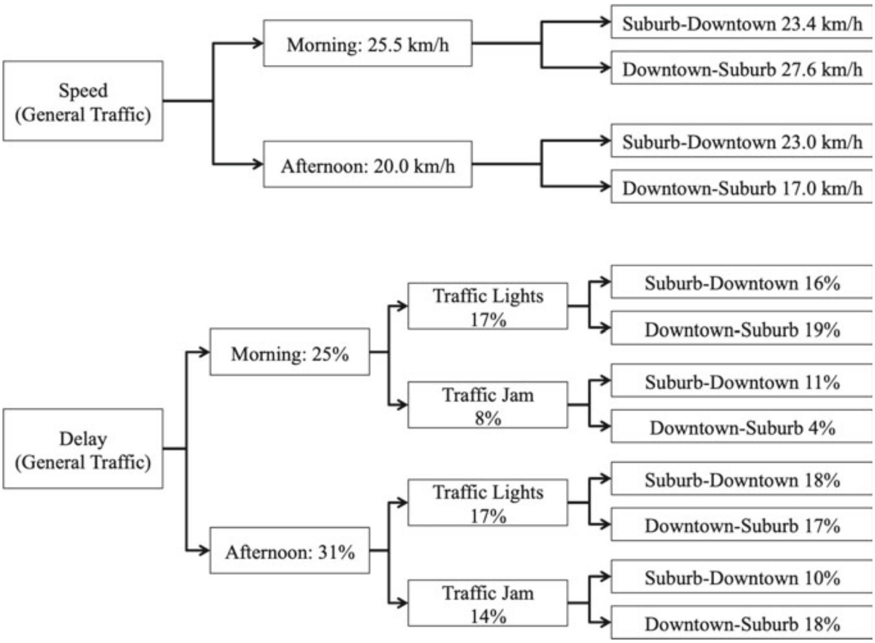


Fig. 13.2 MSVP 2016 traffic speed and delay. *Source* CET (2017)

and flow direction. It also stratified the values in idles caused by traffic lights and by traffic jam.

Yearly Vehicle Emission Calculation

Pollutant particles were calculated and then summed up to establish the emissions of pollutants for São Paulo State. Equation 13.1 gives the yearly vehicle emissions of each pollutant:

$$\frac{gP}{km} \times \frac{km}{year \cdot vehi} = \frac{gP}{year \cdot vehi} \tag{13.1}$$

The gP/km is the emission in grams of pollutant per kilometer from database Emission Factor (CETESB 2017). The term km/(year*vehi) is the average distance of a vehicle for one year originating from the database Use Intensity (CETESB 2017). The result determined the value emitted in grams of pollutant by a vehicle during a year.

To improve the emission estimation model for a city such as São Paulo, the consumption was considered to be at standstill. Equation 13.2 considers periods at standstill and in movement, which included the consumption of the vehicle at idle time.

$$\frac{gP}{km} \times \frac{km}{year \cdot vehi} + \frac{gP}{hour} \times \frac{km}{year \cdot vehi} \times \frac{1}{speed} \times \%Delay = \frac{gP}{year \cdot vehi} \tag{13.2}$$

In Eq. 13.2, before the sum symbol, the term represents the value calculated in Eq. 13.1. After the sum symbol, the hourly emissions of a vehicle resulted in grams of pollutants emitted per year per vehicle. The equation considered the emissions due to the displacement of the vehicle and the emissions due to the stopped vehicle time.

Investigated Fleet Annual Emissions Calculation

The Fleet Database of São Paulo State provided information on the fleet characteristics (CETESB 2017). The average distance traveled by a car, considering the years since its purchase, was obtained from the Intensity of Use and Emission Factor databases (CETESB 2017).

Equation 13.3 shows the emissions segmented in groups by year of manufacture. The sum of the annual emission of all groups according to their respective intensity of use and emission factor results in the total emissions per year.

$$\sum_{n=0}^{40} \frac{gP_n}{km} \times \frac{km_n}{year \cdot vehi} \times vehi_n + \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%Delay = \frac{gP_{fleet}}{year} \tag{13.3}$$

Calculations of Yearly Potential Reduction of Pollutant Emissions by the Start-Stop System

Equation 13.4 includes the annual emission reduction potential of the fleet emission, resulting in a value of grams of pollutant per year which could be reduced during idle periods.

$$\sum_{n=0}^{40} \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay = \frac{pot.red.gP}{year} \tag{13.4}$$

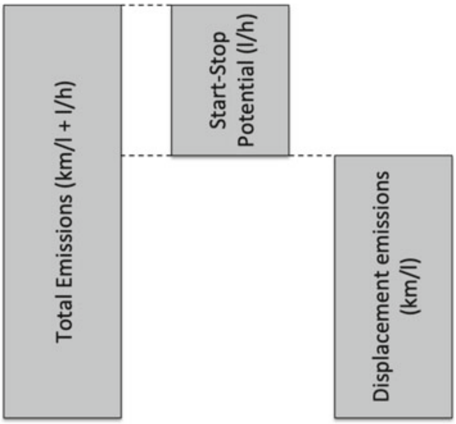


Fig. 13.3 Potential reduction of pollutant emissions gap by the start-stop system. *Source* Author

Calculated emissions can be divided by the kilometers driven and the idle periods. Figure 13.3 shows the potential to reduce emissions through the start-stop system, which does not operate in terms of kilometers per liter of fuel consumed because it operates only in a stopped situation, where there is no distance traveled for the consumption calculation.

Calculation of the Percentage of Potential Reduction of Pollutant Emissions of the Fleet

From the previous calculations it was possible to calculate the percentage relative to total emissions and to verify the potential reduction percentage of emissions (Eqs. 13.5 and 13.6), which allowed the analysis to remain valid regardless of the fleet size analyzed.

$$\frac{\sum_{n=0}^{40} \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay}{\sum_{n=0}^{40} \frac{gP_n}{km} \times \frac{km_n}{year \cdot vehi} \times vehi_n + \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay} = pot\% \tag{13.5}$$

It can also be written in the following reduced form:

$$\frac{\frac{pot.red.gP}{year}}{\frac{gP_{fleet}}{year}} = pot\% \tag{13.6}$$

Calculation Considerations

In order for the databases to provide enough data for the calculations, the following assumptions were considered:

- The mean speed and lag values presented by CET for the main road system represents the whole city of São Paulo.
- The average consumption of a vehicle of the fleet under analysis is 1.098 L per hour. This value was obtained for an ordinary stopped vehicle (gasoline 2.0) from the Argonne National Laboratory (ANL 2018).
- The emission factor base (CETESB 2017) was used to obtain the emission data per stopped hour, multiplying the emissions per kilometer (gP/km) by the autonomy (km/l), obtaining the emission per liter of fuel. This was multiplied by the average fuel consumption of a halted vehicle (l/hour), and hourly emissions were obtained for stopped vehicles.
- Table 1 shows that the particulate matter emission factor has ND values (data not available) for ethanol. These values were changed to zero for calculation purposes, since there are no particulate matter emissions by burning ethanol.
- Data presented as ND in the CO_2 column in the Emission Factor database (CETESB 2017) were considered zero when it represented the absence of flex-fuel vehicles (before 2013) or the extinction of vehicles purely powered by ethanol (after 2006). When the ND values represented an unrealized measurement due to the lack of measurements, but should have a real value, the last values of the nearest year were repeated in order to complete the missing fields.

Results and Discussion

The calculations were performed by equations in the previous sections and the results were obtained for the following pollutants: CO, NMHC, CH4, NO_X, RCHO, PM, CO_2, N_2O. The values in tons and percentage of pollutant reduction emitted during the year 2016, shown in Table 13.4, were obtained through Eqs. 13.1, 13.3 and 13.4. Columns 1 to 4 show the type of pollutant, the total emissions, emissions caused by displacement and the emissions caused by delays. The fifth column presents the potential percentage of emission reduction and was calculated by Eq. 13.5.

In Fig. 13.4 the total emissions and the reduction potential of Table 13.4 are shown graphically for absolute values, sorted by bigger volumes to the smaller volumes, in a logarithmic scale to be able to visualize the magnitude difference between CO_2 and the other pollutants. The markers show the value in percentage in a linear scale.

Among the pollutants considered, there is a greater focus on the potential reduction of CO_2 emissions as it is the main contributor of greenhouse gas emissions. However, the potential reduction of other pollutants could be also interesting, such as PM, which has an impact on the air quality that affects citizens' health.

Table 13.4 Tones of pollutant emitted yearly and respective reduction percentages found by calculations

Pollutant	Total emissions (t/year)	Displacement emissions (t/year)	Delay emissions (t/year)	Emissions reduction potential (%)
CO	48959.6	42865.1	6094.5	12.4
NMHC	5119.9	4474.2	645.7	12.6
CH_4	1368.9	1193.2	175.7	12.8
NO_X	5865.0	5117.6	747.4	12.7
RCHO	270.9	237.6	33.3	12.3
PM	62.4	53.8	8.6	13.7
CO_2	10172427.2	8784086.1	1388341.0	13.6
N_2O	1085.0	935.5	149.5	13.8

Source Author

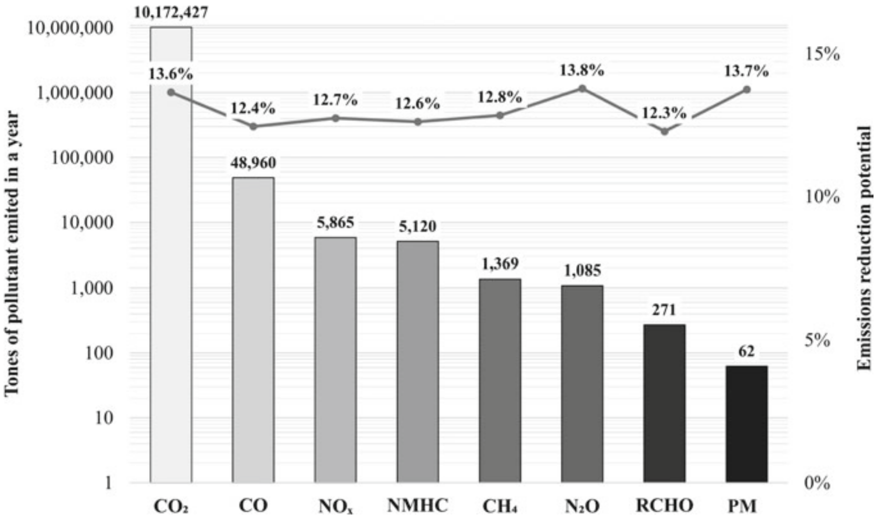


Fig. 13.4 Yearly pollutant emissions and emission reduction potential by pollutant. *Source* Author

No previous study evaluating the potential impact of the start-stop system on the fleet of São Paulo has been found, except for a few studies related to the reduction of pollutant emissions through the start-stop system in Brazil. Da Silva (2013) was the only source that analyzed the emission reduction by the start-stop system. Verzimiassi (2012) evaluated the start-stop operating system and identified the possibility of reducing emissions through the works of Fonseca et al. (2011).

The percentages found in this study are potential and characterize the limit of opportunity for the start-stop system. In simulation, Tsokolis et al. (2016) found a reduction of CO_2 emissions between 2.5% and 4.8% for a turbine medium-sized gasoline vehicle driving the New European Driving Cycle (NEDC). Fonseca et al.

(2011) measured the CO_2 in a diesel vehicle exhaust and found a reduction of 20% in CO_2 emission with the start-stop system switched on compared to the system being turned off.

Verzimiassi (2012) showed that the start-stop system generally reduces 6% of CO_2 emissions, reaching 8% in urban traffic and up to 25% in heavy traffic. Da Silva (2013) found a reduction in CO_2 emissions of 12.8% for the New York City Cycle (NYCC) and 10.1% for the Japanese 10–15 cycle, both testing a diesel vehicle with the start-stop system turned on and off. These authors also tested out-of-laboratory fuel consumption in real traffic situations on Ontario's streets and found a 7% reduction when comparing 1,500 km with the system switched on to 1500 km driven with the system shut down. The CO_2 reductions obtained were almost identical to the percentage reduction in consumption, obtaining 12.7% for the NYCC and 10.1% for the Japanese 10–15.

Differences between reduction potentials for different cycles may be caused by the time at stop situation that each cycle considers. The FTP-75 considers short periods stopped. The NEDC and Japanese 10–15 consider longer stops compared to the FTP-75. The NYCC is based on heavy traffic with long downtime, characteristic of big cities.

Routes studied could also interfere in the results. The routes inspected in the MSVP are characterized by main roads which have fewer intersections, which leads to the belief that adjacent roads have a bigger delay index that could increase the reduction pollutant potential.

Despite vehicle emissions being reduced significantly due to the implementation of the PROCONVE strategies, the imposed targets do not specify how the emissions reduction should occur. However, the need to continue reducing emission factors makes it natural for the market to look for other possibilities besides increasing the engine's efficiency.

To ensure maximum emission limits, the start-stop system has been used even for high power vehicles due to the reduced fuel consumption. However, the global outlook points to the extinction of combustion vehicles, which shows the start-stop system as a transitional technology to the hybrid, leading to the belief that advances in fuel cells and electric vehicles will be responsible for the disuse of combustion vehicles.

Effects of Considered Values

Some values used in the calculations were based on assumptions; how each of the values of these assumptions influenced the final result was verified. A variation of the consumption at standstill, 1.098 L per hour, changed exclusively the delay emissions and presents a direct linear relation: if the consumption at standstill doubles, the delay emissions will double. However, the potential percentage will increase, but not necessarily in the same proportion because it also depends on consumption displacement. The same occurred with the delay percentage increase and with the average speed reduction.

Conclusion

It was concluded that the start-stop system presents relevant potential for reducing vehicular emissions in the city of São Paulo once potential reduction values between 12.3% and 13.8% were found. The efficiency of the transportation sector is a critical factor in achieving the greenhouse gas emissions reduction targets because the sector contributes greatly to global CO_2 emissions.

More studies are needed to increase the accuracy of these work results since no experimental studies were found which test the start-stop system performance in the city of São Paulo. It is believed that more samples of diverse routes, beyond the 28 routes from MSVP, would allow one to obtain more accurate values for speed and delays of São Paulo city traffic, and that data from applications such as Waze and Google Maps could improve accuracy results.

In addition, technical and economic studies are required to obtain costs of implementing the start-stop system and the possible return on investments that can be generated by the inclusion of the system in the fleet of lightweight vehicles.

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