Environmental impact of motorcycle replacement exhaust systems in Sao Paulo City

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Abstract

There are about 900,000 motorcycles in the Sao Paulo Metropolitan Region (SPMR), comprising 12.2% of the vehicle fleet in 2014, with a 15% presence in the traffic flow. They contribute 23% of the Equivalent Noise Level (Leq) of road noise and are responsible for 21% of all CO, 12.8% of HC and 2.1% of NOx emissions. Non Original Exhaust Systems (NOES) can be found in 16% of the motorcycles in SPMR; these usually have no catalyser and fewer internal parts than an original exhaust system from the Original Equipment Manufacturer (OEM), in order to reduce gas flow counter-pressure and to produce a typical "popping" sound. According to users, the main reasons for using NOES are "safety", "I like loud noise" and "performance". Regarding noise, motorcycles equipped with NOES have a sound level 12.8 dB(A) higher than those with original exhaust systems and correspond to 62% of Leq generated from motorcycles. The use of NOES for professional "moto freighters" can result, among other occupational diseases, in Noise-Inducted Hearing Loss. With respect to gaseous emissions, NOES bring an individual increment of 1.2 to 12 times the emissions of CO, HC and NOx, compared with OEM mufflers; that adds yearly in SPMR about 1,277 t of CO, 230 t of HC and 310 t of NOx, drawing motorcycles with this equipment back to levels before Brazilian phase M3, equivalent to Euro 3.
Keywords: noise, gaseous pollution, tampered motorcycles, exhaust system.

1 Introduction

In the past, motorcycles in Brazil were seen just as "hobby vehicles"; in the 1990s there were only two manufacturers, and internal sales amounted to just 53,000

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units/year. This tendency changed in the late 1990s and early 2000s, reaching its upper point in 2011, when 1.9 million units were sold; however, recent gross production has decreased somewhat to about 1.4 million in 2014 [1]. The growth in the motorcycle fleet from 2004 to 2014 was about 223%, much greater than the 121% growth in the general fleet (cars plus heavy duty vehicles plus motorcycles) and the 12% growth in population [1]. This can be explained by a preference for individual over public transportation due to the precariousness of the latter and the emergence of a new professional category: the moto-freighters, who are also known in Brazil as "motoboys", dedicated to delivering small goods, documents and fast food [2, 3].

The impact of the growing fleet of motorcycles on the urban environment was recognized by the Brazilian Government, which established regulations, firstly for noise in 1993 and in a second step in 2003 for gaseous emissions for new motorcycles sold in the internal market, including them as part of the Air Pollution Control Program for Motor Vehicles (PROCONVE), known as the Air Pollution Program for Motorcycles and similar (PROMOT) [4]. However, a problem related to in-use motorcycles persists, the same faced in many parts of the world: the change of original mufflers (OEM) for Non-Original Exhaust Systems (NOES), replacement exhaust systems sold in the aftermarket and used by riders in order to improve performance and/or produce more noise. Their particular characteristics undermine all the gains brought by regulations and contribute to worsening the urban environment of the Sao Paulo Metropolitan Region (SPMR).

The objective of this paper is to quantify the environmental impact on SPMR with regard to noise and gaseous emissions from motorcycles equipped with NOES.

2 Methods

To analyse motorcycles' environmental impact, this work is divided into four parts. The first part calculates their gaseous emissions in SPMR; secondly the Noise Equivalent Level (Leq) in an arterial road close to downtown Sao Paulo City is evaluated; thirdly, NOES themselves are analysed as a source of noise and gases, while the fourth part estimates the impact on noise and gases of the use of NOES in SPMR.

The first part of the analysis is based on CETESB (Environmental Company of Sao Paulo State/Brazil) gaseous emissions inventory methodology, where general vehicular gaseous emission are calculated weighting fleet quantity and composition, fuel consumption and mileage average among other data stored since 1979 to now. It was performed on these spreadsheets a specific study focused on motorcycles with NOES.

The second part was developed in the field, measuring Leq from cars, motorcycles and buses, calculating each particular Leq according to traffic flow composition, and determining the contribution made by motorcycles to urban noise. To register the specific Leq for each vehicle category, the Sound Level Meter (SLM) was set in Leq mode and started typically when traffic flow consisted only of cars or buses or motorcycles and was stopped when the flow changed,

meaning here that "specific Leq" is a sum of short measurements which results in a respective sound level. It was also taken the Sound Level Pressure (Lp) of a sample of fifty motorcycles to determine how many them produce more than 80 dB(A), in order to identify outliers. This cut-off point (80 dB(A)) was chosen because our previous studies had shown that motorcycles with original parts (OEM) when running in typical traffic flow tend to produce less than 80 dB(A), on other hand motorcycles with NOES tend to be above this level.

The third part of this work, analysing the NOES, is divided into two steps: first, field measurements of motorcycles' noise when running and, in sequence, evaluating the stationary noise of these same vehicles, comparing those with original equipment from the OEM with those equipped with NOES. The SLM was set in Lp mode to register running noise and, for the stationary noise, it was set according to ISO 5130, in Lmax mode and 0.5 m away from the exhaust system with the engine running at 1/2 of the rated maximum power speed. Brazilian Environmental Law establishes that all manufacturers or importers must provide information on their own website specifically regarding engine speed and homologated stationary noise limits for each model sold in Brazil [4]. The second step, concerning NOES gaseous emissions, was performed using a dynamometer with a 2009 model, phase PROMOT M3, equivalent to Euro 3, and a 2014 model (PROMOT M4 or Euro 4), within their respective test cycles (European Directive 97/24 or WMTC). Samples were taken in two modes: running with an OEM exhaust system and running with this same system without a catalyser, because that is the main difference between OEM and NOES in respect of gases.

The fourth and final part of this work estimates NOES' environmental impact by inserting NOES specific data on noise and gases emissions into the spreadsheets and analysing these results.

3 Results and discussion

3.1 Gaseous contribution

Sao Paulo State has the biggest motorcycle fleet in Brazil, about 5 million or 21% of all motorcycles in Brazil [1]. Just in SPMR are registered almost one million units; this is 20% of the state fleet and represents 11% of all registered vehicles [5]. SPMR traffic flow is composed of about 80% of light duty vehicles, 15% of motorcycles and 5% of heavy duty vehicles, mainly buses (3 to 4%) [6]. In comparison with other regions, the presence of motorcycles in SPMR traffic is a median term; it is more than in the USA (3% of the flow), Canada (5%) and Europe (11.5%) but much less than in Asian countries such as Taiwan (68%), India (72%) and Indonesia (80%) [7, 8], and, like these Asian countries, there is a prevalence (96%) of small capacity engines, below 250 cm^3 [1, 7].

The main vehicular gaseous pollutants in SPMR are hydrocarbons (HC) from unburned and evaporated fuel; nitrogen oxides (NOx) and carbon monoxide (CO) from engine combustion, besides aldehydes (CHO), sulphur dioxide (SO_2) and particulate matter (PM) [9]. Figure 1 shows the relative contribution of each type of vehicle in the generation of pollutants, with motorcycles producing 21.0% of

all CO, 12.8% of HC and 2.1% of NOx; their annual emissions amount to about 34.2 t of CO, 4.4 t of HC and 1.1 t of NOx. The pollution caused by motorcycles has a greater weight than their presence in the traffic and their fuel consumption so if many motorcycles are present in the traffic, can be expected higher levels of CO and HC.

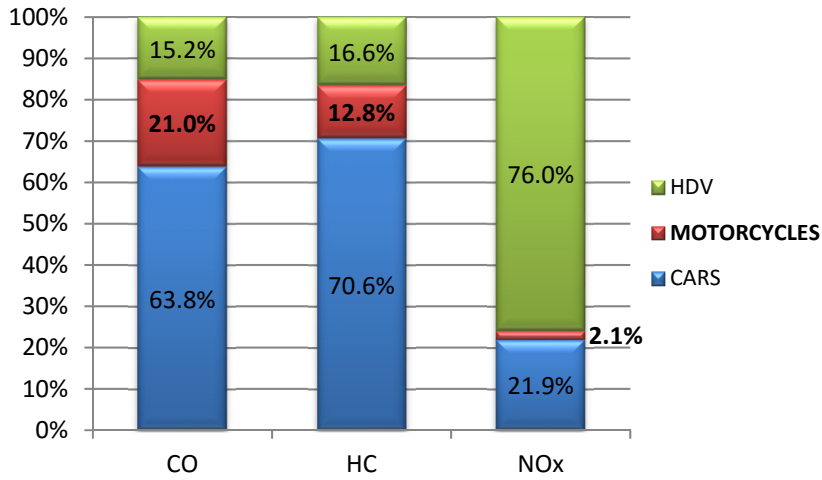

Figure 1: Relative contribution to gaseous emissions in SPMR ([9] adapted).

3.2 Leq contribution

Field measurements were taken on an arterial road in downtown Sao Paulo City, with four lanes of intensive flow at typical urban velocities (25-50 km/h) and a massive presence of cars, motorcycles and buses. The results obtained are shown in Table 1 and Figure 2.

Table 1: Traffic composition and measured data.

Categories	Traffic flow [6]	Specific Leq dB(A)	Contribution to Leq	> 80 dB(A)
Cars	80%	72.6	64%	2%
Motorcycles	**15%**	**75.5**	**23%**	**16%**
HDV	5%	77.5	12%	31%
General Leq (calculated):		***73.6***		
General Leq (measured):		***73.8***		

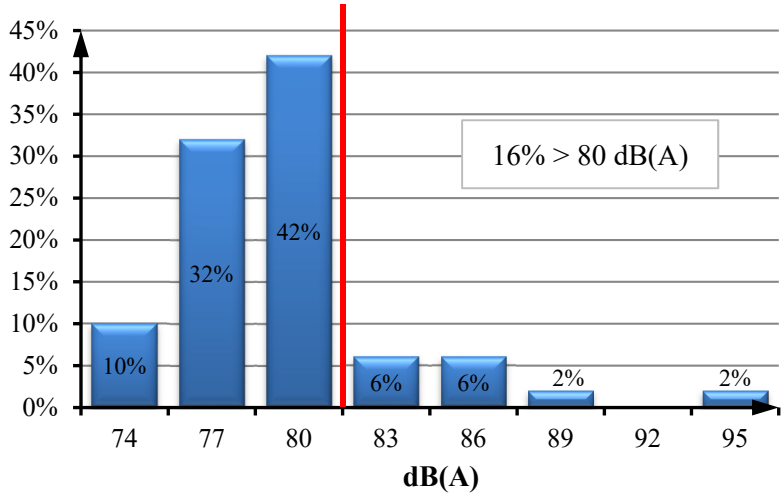

Figure 2: Proportion of motorcycles observed on the road and respective noise levels.

Motorcycles are the second main source of traffic noise, with a specific Leq of 75.5 dB(A), significantly higher than that of cars and close to that of HDV. The amount recorded above 80 dB(A) is also high, 16%, mainly due to the use of NOES (92% or more) and rarely due to super sport or custom models. It has also been observed that some motorcycles emit more than 90 dB(A). As a result of this, although the quantity of motorcycles in the streets is less than that of cars, their global influence is significant: 23% of all Leq. This means, for example, that if the presence of motorcycles in traffic flow increases to 37%, they will be responsible for 50% of general Leq.

3.3 NOES' influence on noise and gaseous emissions

NOES in Brazil usually have no catalyser and fewer internal parts than a system from an OEM, in order to reduce gas flow counter-pressure, but generating much more noise. There is no specific legislation now in force in Brazil regarding NOES noise and gas limits so manufacturers avoid using catalysers to keep the selling price lower than that of an OEM. The lack of in-use inspections also contributes to owners choosing cheaper-but-polluting NOES instead of original parts.

There are three main types sold in the Brazilian aftermarket: the "popper" type, shown in Figure 3, is the best-seller muffler with about 90% of the sales. Due to the fact that it has no internal components to absorb noise, it produces a loud "popping", especially when the rider runs the engine in median-high velocities and suddenly closes the throttle. Others types are "similar to the original", reproducing the OEM's internal construction and external design and "sport", just a punched pipe with a box outside it, filled with glass wool.

Figure 3: Internal view of a "popper" muffler.

3.3.1 Noise

The noise level in a street close to a spare parts shop was evaluated, when motorcycles were approaching in low velocity, at about 20 to 25 km/h, and again when they were stopped in the parking zone. NOES were recognized by their sound profile, quite different from that of OEMs, by observation while measuring stationary noise and by asking the rider about which kind of muffler was assembled in the vehicle. The results are shown in Table 2 and Figure 4.

Table 2: NOES noise emission.

Noise when running (reference: OEM average)	+ 12.8 dB(A)
Noise above 80 dB(A) when running	81%
Stationary noise above homologation limits	100%
Stationary noise level above homologation limits	+ 8.5 dB(A)

The noise increment produced by just one NOES is very high because +12.8 dB(A) is equivalent to around 20 OEM vehicles running together. The level of annoyance is also huge, with 81% NOES producing more than 80 dB(A), even at very low velocities. Another important point is that 100% of NOES were condemned at stationary noise control. However, because it is very easy to change

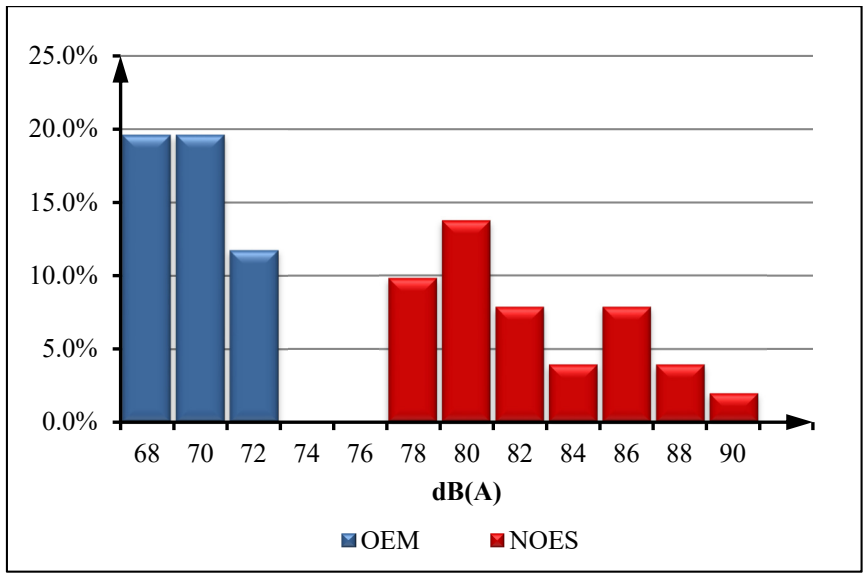

Figure 4: Noise of motorcycles running with OEM parts and with NOES.

a motorcycle exhaust system, which is usually kept in place by just three bolts, it is hard for a pre-scheduled vehicular inspection to control this problem.

During the interviews with the riders, there was a question about the reasons for using this kind of muffler. The answers were:

- Safer to run quickly among cars:.. 43%
- I like loud noise:……..... 23%
- Better performance:……. 17%
- Others:…….. 17%

The main reason, "safety" or "to be heard by others while running fast among cars", is very relative: the sound projection of a motorcycle is mainly to the rear, secondly to the sides and minimally to the front [10]. On the other hand, the worst points for safety are the blind spots around a car, usually at the sides, when a loud exhaust system can be useful to alert car drivers.

3.3.2 Gases

Brazilian gaseous emissions' phases are close to the European development, although with distinctive names or in different periods. Table 3 has a summary of these phases.

Because NOES have no catalysers it was expected that these exhaust systems would push emissions up beyond the M3/Euro 3 limits, even in an M4 motorcycle. This was partially true because, for CO, the tested vehicles exceed or are very close to the M3 limits and, for NOx, they greatly exceed these, as summarized in Table 4. For HC, they are still adhering to legal parameters, but, with a huge

Table 3: Brazilian motorcycle phases for gaseous emissions [4].

Brazilian phase	Europe equivalent	Period	Limits (g/km) (engine < 150 cm^3)			Technology
			CO	HC	NOx	
M1	Euro 1	2003-2006	13.0	3.0	0.3	Carburettor + Adjustments
M2	Euro 2	2006-2008	5.5	1.2	0.3	Carburettor + Adjustments
M3	Euro 3	2009-2014	2.0	0.8	0.15	Carburettor or Fuel injection + catalyser
M4	Euro 4	2014-now	2.0	0.8	0.15	Fuel injection + catalyser

Table 4: Comparison of OEM and NOES emissions.

		Model 2009 125 cm^3 Phase M3/E3	Model 2014 150 cm^3 Phase M4/E4
CO (g/km)	OEM	1.818	0.522
	NOES	2.241	1.939
	M3/M4 limit	2.0	
	Increment	1.23 x	3.71 x
HC (g/km)	OEM	0.257	0.069
	NOES	0.509	0.253
	M3/M4 limit	0.8	
	Increment	1.98 x	3.67 x
NOx (g/km)	OEM	0.085	0.063
	NOES	0.417	0.735
	M3/M4 limit	0.150	
	Increment	4.91 x	11.67 x

increment, particularly to the 2014 model, it means that use of NOES can degrade environmental quality back to 2008 levels or earlier: a loss of eight years of vehicle engineering development.

3.4 NOES' environmental impact

The observed presence in the traffic flow of 16% of motorcycles with NOES and exceeding 80 dB(A) is the basis for estimating the environmental impact. In Europe and Japan this proportion is worst, according to ACEM [11]; in Europe 35% of motorcycles and 65% of mopeds (51% in general) have illegal exhaust systems and in Japan these amount to about 40% [12]. So, all estimations here were made upon the observed proportion and also for an increment to 35% of NOES in the SPMR fleet.

Regarding noise, these 16% of NOES are responsible for 62% of the 75.5 dB(A) of Leq generated by motorcycles. The increment to 35% of NOES in the motorcycle fleet could raise specific Leq to 77.7 dB(A) (+2.2 dB) and push up general Leq from 73.6 to 74.2 dB(A) (+14.4%).

In respect of gases, NOES is responsible for a rise in all emissions but this rise is not so high because catalysers were introduced in Brazilian motorcycles just after 2009. Nevertheless, there is a tendency for these emissions to grow even more as, at the present time, NOES (without catalysers) are replacing newer OEMs with built-in catalysers exhaust systems. In Table 5 the impact of NOES can be seen, especially in HC (+ 1,277 t/year) and CO (+ 5.2%), and it is estimated that 35% of motorcycles with NOES will produce an additional HC emission of 2,793 t/year and an impact of + 11.4% in CO. The absolute increase in NOx is very high, but the level of influence on the environment is not so high due to the fact that motorcycles contribute only 2% of general NOx emission.

Table 5: Gaseous emissions in SPMR in 2014.

		Motorcycles (actual)	With 35% NOES
HC (t/year)	OEM	34,272	34,272
	NOES	35,549	37,065
	Difference	+ **3.7%**	+ **8.1%**
Increment (t/year):		*1,277*	*2,793*
CO (t/year)	OEM	4,408	4,408
	NOES	4,638	4,912
	Difference	+ **5.2%**	+ **11.4%**
Increment (t/year):		*230*	*504*
NOx (t/year)	OEM	1,134	1,134
	NOES	1,444	1,811
	Difference	+ **27.3%**	+ **59.7%**
Increment (t/year):		*310*	*677*

4 Conclusions

NOES' main problems are related to noise and gaseous emissions, and it is possible to see a great increase in all pollutants and noise pressure, harking back to levels before the introduction of M3/Euro 3. The presence of 16% of NOES in the motorcycle fleet is lower than in Europe and Japan, but the environmental impact is higher because the Brazilian fleet is bigger and the impact is likely to get worse with the growing tendency of the fleet to use NOES.

Although moto riders can argue about safety or personal preferences in their motorcycles' sound, NOES is delivering a huge impact on the SPMR urban environment that cannot be neglected. Another important point is that the same rider who changes his motorcycle's exhaust system is the first person to be affected by his own sound pollution, sometimes subjecting himself to levels of 90 dB(A) and higher. The professional moto-freighters ("motoboys") present the worst case because they are subject to many stressor agents for Noise-Induced Hearing Loss: high noise level in high frequencies, for many hours and in the presence of vibration from the engine and suspension.

The high level of increasing gas and noise emissions due to NOES is a degradation factor of the SPMR environment that demands strong and urgent action to reduce or even banish this component when sold or used with no catalyser and unable to fulfil legal noise limits.

Definitions/abbreviations

CETESB – Environmental Company of Sao Paulo State, Brazil
CHO – Aldehydes
CO – Carbon monoxide
ETHA – Department of Transport Systems' Evaluation of CETESB
HC – Hydrocarbons
HDV – Heavy Duty Vehicles: vehicles for carriage of people or goods with a maximum authorized mass above 3,500 kg, such as buses and lorries.
Leq – Equivalent Noise Level: an average that corresponds to the same energy at a steady level during the measurement of a fluctuating sound.
Light Duty Vehicle – a vehicle to carry passengers or goods with a maximum authorized mass below 3,500 kg, e.g. cars, vans, SUVs.
Lp – Sound Level Pressure
NOES – Non Original Exhaust System: a set comprising pipe plus muffler sold in the aftermarket.
NOx – Nitrogen oxides
OEM – Original Equipment Manufacturer: original part supplied in the vehicle or sold by the manufacturer.
PM – Particulate matter
PROCONVE – Air Pollution Control Program for Motor Vehicles
PROMOT – Air Pollution Program for Motorcycles and similar
SLM – Sound Level Meter
SO_2 – Sulphur dioxide

SPMR – Sao Paulo Metropolitan Region: the biggest metropolitan area in Brazil, covering Sao Paulo City plus 38 other cities; in 2014 about 21 million people were living in an area of almost 8,000 km^2.
WMTC – World Motorcycle Transient Cycle: standard procedure to test and measure motorcycles gaseous emission in laboratory.

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