Environmental Impact Assessments of Generator Sets

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ENVIRONMENTALITY
Tecnologia com Conceitos Ambientais

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1. Introduction

This work refers to the emission control program for generator sets discussed with the members of AFEEVAS, ABIMAQ, government agencies and other members of the AEA, which will be proposed to CONAMA.

The estimate of the environmental impact of the generator sets cannot be made in the traditional way due to lack of information on the number of generators in operation in Brazil and the scrapping rate of this type of machine.

Alternatively, environmental impacts can be estimated only in terms of the **Annual emissions caused by the generators sold**, calculated for the current scenario (with machines manufactured without emission control) and compared to a future scenario that would occur after the implementation of the suggested limits in the entire generator park, which will show the effectiveness of the proposed measures, but not the final results in the atmosphere, considering the current scrapping rate and future growth in the number of machines.

The proposition of North American Tier 4F limits, for the generator sets responsible for almost 90% of the energy generation by this segment, gives high quality to the proposal we developed, however, the adoption of Tier 2 and Tier 3 limits for the remaining cases, despite presenting emission reductions of more than 70%, still constitute points that deserve some specific comments for the application of generators in restricted places or with large circulation of people, where it may be necessary to employ Tier 4F models, even in emergency generators, as they will be available on the market.

Also in cases where energy generation is predominantly made from diesel engines, as is already the case in several cities in Brazil, commercial establishments and even residential buildings, the supply of electric vehicles should be admitted only if these facilities have Tier 4F generators, since the electrification of vehicles needs to rely on energy sources as clean as the most modern vehicle engines. If generators do not follow this trend, electric mobility will be greatly impaired and will not make sense in these situations.

These aspects should be mentioned in the RIA (Regulatory Impact Analysis) and can be conveniently discussed in comparative terms with P8 vehicles operating in the same locations, which will be a strong argument in favor of the Program as it is designed.

2. Evaluation of the fleet of generators sold in Brazil by category and proposal of technological standards

ABIMAQ, an association that brings together the main Brazilian companies in the sector, surveyed the number of generators sold and installed in Brazil in the last twenty years and provided a table with the number of machines, by power class and by type

of use (Prime – COP - Stand by[1]), the distribution of which has been estimated in proportion to the sales statistics of its member companies[2].

Table 1 - Number of national machines distributed according to ABIMAQ statistics

		p < 10 kVA	10 kVA ≤ p < 30 kVA	30 kVA ≤ p < 75 kVA		75 kVA ≤ p < 150 kVA	150 kVA ≤ p < 250 kVA	250 kVA ≤ p < 400 kVA	400 kVA ≤ p < 550 kVA	550 kVA ≤ p < 750 kVA		750 kVA ≤ p < 1000 kVA	P ≥ 1000 kVA
horas/ano	kVA médio	7	20	41,25	63,75	112,5	200	325	475	600	700	875	1300
50	Stand by	6.287	27.524	21.144	21.144	46.017	66.464	34.115	32.496	8.531	8.531	1.748	538
1350	Prime	1.182	2.410	1.508	1.508	2.834	12.406	1.799	6.356	5.133	5.133	593	288
6307	COP	4.643	9.286	4.744	4.744	750	1.298	421	3.251	178	178	543	327

The "emergency" category is distinguished from the others by being intended for the supply of energy for very short periods, which rarely exceed 50 hours/year and has a low cost because they do not need to attend major durability requirements for heavy services.

The energy production of these generators was estimated according to these basic characteristics to identify the most significant categories and types of service **between generators** and that they should be priority targets for the application of the best practical technology available in the Brazilian market. Table 2 presents the utilization factors for the three service categories and table 3 shows the annual electricity production and the percentage of total generation for each category of generator sets associated with the respective power classes and service types. The COP use factors consider 90% of the maximum total of 8,760 hours per year (365*24*0.9=7,884), while the others were estimated by the manufacturers.

Table 2 - Utilization factors

Categoria	Horas de trabalho/ano	% carga	Horas equivalentes em Potência Nominal
Prime	1500	90%	1350
COP	7884	80%	6307
Emergência	50	100%	50

[1] **Prime** or **Prime Power** – continuous use with unlimited operating time, ideal for variable loads and with temporary overload capacity (10% for up to 1 hour every 12 hours);

COP or **Continuous Power** - for continuous and constant operation without overloading;

Stand by or **emergency** – suitable to run for a few hours or even days, operating a maximum of 200 hours per year and with variable load.

[2] The identification of the generators is made by the electrical power given in kVA, which corresponds to a mechanical power of the motor of 80% of this value, in kW.

Table 3 – Annual Energy Production of the Installed Farm, in 1000*kVA (number of machines * hours/year * average power)

		p < 10 kVA	10 kVA ≤ p < 30 kVA	30 kVA ≤ p < 75 kVA		75 kVA ≤ p < 150 kVA	150 kVA ≤ p < 250 kVA	250 kVA ≤ p < 400 kVA	400 kVA ≤ p < 550 kVA	550 kVA ≤ p < 750 kVA		750 kVA ≤ p < 1000 kVA	P ≥ 1000 kVA
horas/ano	kVA médio=	7	20	41,25	63,75	112,5	200	325	475	600	700	875	1300
50	Stand by	2.200	27.524	43.608	67.395	258.846	664.640	554.369	771.780	255.915	298.568	76.475	34.970
1350	Prime	11.170	65.070	83.977	129.782	430.414	3.349.620	789.311	4.075.785	4.157.730	4.850.685	700.481	505.440
6307,2	COP	204.990	1.171.373	1.234.256	1.907.486	532.170	1.637.349	862.983	9.739.736	673.609	785.877	2.996.708	2.681.191

Environmental Impact Factors

50	Stand by	0,00%	0,06%	0,09%	0,14%	0,56%	1,43%	1,19%	1,65%	0,55%	0,64%	0,16%	0,07%
1350	Prime	0,02%	0,14%	0,18%	0,28%	0,92%	7,18%	1,69%	8,74%	8,92%	10,40%	1,50%	1,08%
6307	COP	0,44%	2,51%	2,65%	4,09%	1,14%	3,51%	1,85%	20,89%	1,44%	1,69%	6,43%	5,75%
Total por faixa de potência		0,47%	2,71%	2,92%	4,51%	2,62%	12,12%	4,73%	31,28%	10,91%	12,73%	8,09%	6,91%

The above classification, given as a percentage of the annual power generation of the national park of generator sets, allowed us to establish "*Environmental Impact Factors*", proportional to the generation of energy, as criteria of importance and priority for the environmental control of generators, and a consensus was reached on the Technological standards and deadlines for its development and implementation in Brazil, as shown in table 4.

An important aspect in this discussion is that the mode of operation of emergency generators, intermittent and short-duration, hinders the proper functioning of gas aftertreatment systems for emission control, requiring specific operating procedures to control the cleaning (regeneration) of the DPF filter and the adequate heating of the catalyst, usually present in Tier 4F level machines. For this reason, it was decided to use the Tier 2 and Tier 3 standards as the general application of this category of machinery.

Table 4 - Technological standards and implementation deadlines

		p < 10 kVA	10 kVA ≤ p < 30 kVA	30 kVA ≤ p < 75 kVA		75 kVA ≤ p < 150 kVA	150 kVA ≤ p < 250 kVA	250 kVA ≤ p < 400 kVA	400 kVA ≤ p < 550 kVA	550 kVA ≤ p < 750 kVA		750 kVA ≤ p < 1000 kVA	P ≥ 1000 kVA
horas/ano	kVA médio=	7	20	41,25	63,75	112,5	200	325	475	600	700	875	1300
50	Stand by	24 meses - TIER 2 - 6,1%			24 meses - TIER 3 - 5%					24 meses - TIER 2 - 1,4%			
1350	Prime				60 meses - TIER 4F - 72,7%							84 meses - TIER 4F - 14,8%	
6307	COP												

With this proposal, obtained by consensus in the AEA Working Group, it is possible to limit investments, while enabling a high level of control, as 88% of the energy generation by this segment can already be served by Tier 4F level generators.

3. Estimates of annual emissions from generator sets

Table 5 presents the annual emissions of pollutants from the same generator park as if they were new and in accordance with the proposal under analysis here.

These emissions were estimated from the energy generation shown in table 3 and the emission factors associated with table 4 for each technological level and power class, taken according to the North American standards Tier 2 to Tier 4F, as appropriate. The lines of the totals by power range were classified by color scales, with green for the least significant values and red for the largest, while in the upper lines the colors corresponding to the technological standards indicated in Table 4 were maintained.

Table 5 – Estimates of annual emissions from the generator park - ton/year (as proposed)

	horas/ano	kVA médio	p < 10 kVA	10 kVA ≤ p < 30 kVA	30 kVA ≤ p < 75 kVA		75 kVA ≤ p < 150 kVA	150 kVA ≤ p < 250 kVA	250 kVA ≤ p < 400 kVA	400 kVA ≤ p < 550 kVA	550 kVA ≤ p < 750 kVA		750 kVA ≤ p < 1000 kVA	P ≥ 1000 kVA
CO ton/ano	50	Stand by	14	145	174	270	1035	1861	1552	2161	717	836	214	98
	1350	Prime	71	344	336	519	1722	9379	2210	11412	11642	13582	1961	1415
	6307	COP	1312	6185	4937	7630	2129	4585	2416	27271	1886	2200	8391	7507
	Total por faixa de potência		1.398	6.674	5.447	8.419	4.886	15.825	6.179	40.844	14.244	16.618	10.566	9.020
HC ton/ano	50	Stand by	2	20	32	31	103	263	220	306	167	195	50	23
	1350	Prime	8	48	62	20	65	509	120	620	632	737	106	77
	6307	COP	152	871	917	290	81	249	131	1480	102	119	455	408
	Total por faixa de potência		162	939	1.012	341	249	1.021	471	2.406	902	1.052	612	507
NOx ton/ano	50	Stand by	12	145	229	222	726	1864	1554	2164	1184	1381	354	162
	1350	Prime	59	342	441	42	138	1072	253	1304	1330	1552	224	162
	6307	COP	1078	6158	6488	610	170	524	276	3117	216	251	959	858
	Total por faixa de potência		1.148	6.644	7.159	874	1.034	3.459	2.083	6.585	2.730	3.185	1.537	1.182
MP ton/ano	50	Stand by	1	18	21	22	62	106	89	123	41	48	12	6
	1350	Prime	7	42	40	2	7	54	13	65	67	78	11	8
	6307	COP	131	750	592	31	9	26	14	156	11	13	48	43
	Total por faixa de potência		140	809	654	54	78	186	115	345	118	138	71	57

It is important to note that the power categories between 10 and 50 kVA appear to be critical after the full implementation of the program, however these classes are the first to be implemented, in 24 months, standing out with emission reductions between 70% and 80% as shown in table 6, but lose this image from the introduction of the Tier 4F limits, later, in the other categories.

In addition, new estimates of emissions from the same generator sets were made based on the emission limits of heavy vehicles in the P2 phase of PROCONVE to characterize the base scenario, representative of the current situation without emission control. The effectiveness of the proposed program was determined by comparing the base scenario with that resulting from the application of the suggested standards, which exceeds the general index of 90% for the most significant pollutants from Diesel engines, namely PM, NOx and HC, as indicated in table 6.

This analysis demonstrates that the implementation of Tier 4F emission limits in the main power classes and categories will significantly reduce the current environmental impacts of generator sets **as a whole**, acting more intensely in the Prime and COP categories. The permanence of Tier 2 and Tier 3 limits for emergency generators and

those with power below 50kVA will make them relatively more significant and may merit future updates.

However, in the case of the punctual impact of a generator set on a microenvironment, such as in a garage or patio where people are directly exposed to its emissions, the problem may require additional limitations in the licensing of the facilities, depending on the configuration of the environment and the environmental limits applicable to the fixed emission sources.

Table 6 –Annual emissions from generators and program effectiveness – ton/year

CENÁRIO BASE (PRODUÇÃO ATUAL SEM CONTROLE)

Categoria	CO	HC	NOx	MP
Stand by	39.121	7.078	35.208	2.445
Prime	245.113	44.350	220.602	15.320
COP	312.675	56.575	281.407	19.542
Total	**596.909**	**108.003**	**537.218**	**37.307**

CENÁRIO APÓS A IMPLANTAÇÃO TOTAL DA PROPOSTA

Categoria	CO	HC	NOx	MP
Stand by	9.078	1.412	9.996	549
Prime	54.593	3.005	6.919	393
COP	76.449	5.256	20.705	1.822
Total	**140.120**	**9.674**	**37.620**	**2.764**

REDUÇÕES POTENCIALIZADAS PELO PROGRAMA

Categoria	CO	HC	NOx	MP
Stand by	77%	80%	72%	78%
Prime	78%	93%	97%	97%
COP	76%	91%	93%	91%
Total	**77%**	**91%**	**93%**	**93%**

4. Analysis of individual exposure in the vicinity of a generator

The simplest and most intuitive analysis of the impact of a generator working in the vicinity of people is the comparison with vehicles of the same power traveling at the same distance from the people exposed. The graphs in Figure 1 compare the pollutant emissions of each generator category with those of vehicles in accordance with stage P8, expressed as "equivalent number of P8 vehicles" of the same power, with the exception that there are no heavy-duty vehicles with less than 56 kW. The P8 (or EURO VI) limits represent the best state of the art in the world, mandatory in Brazil since 2023, and which already offer minimized conditions of environmental impact, considered sufficient to ensure air quality in the urban environment.

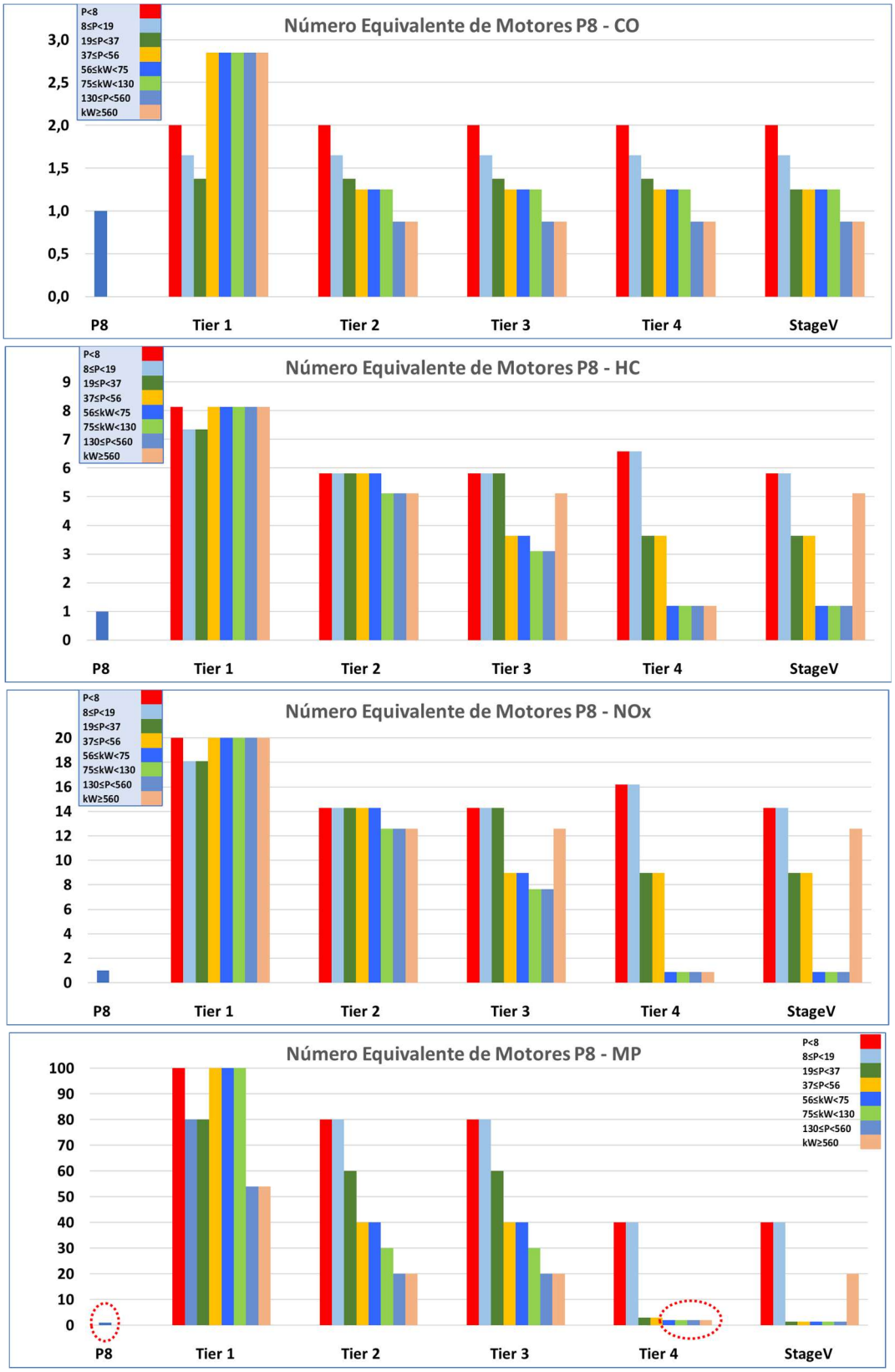

Figure 1 – Emissions from a generator in an equivalent number of P8 vehicles, by power range and technological level.

By way of illustration, these comparisons have been extended to the current European Stage V limits for off-highway machines and generators, as an alternative reference. In general, the following characteristics of the proposal for the Brazilian regulation of emissions for generators can be observed:

a. In terms of CO, the equivalence is between 0.9 and 2.0 P8 vehicles of the same power, even for small generators that will be Tier 2. It is observed that the emission of this pollutant is the one that has the least environmental significance in Diesel engines.

b. For hydrocarbons, which are mainly associated with the characteristic odor of diesel engine gases, we have 3 categories to consider:

   - the COP and Prime generators with power greater than 56 kW (Tier 4F) are equivalent to 1.2 P8 vehicles of the same power, which is quite acceptable from the point of view of nuisance.
   - all generators with a power of less than 56kW, as well as emergency generators with a power of more than 560 kW, will be Tier 2 and equivalent to 5 or 6 P8 engines of the same power.
   - emergency generators with powers between 56kW and 560kW (Tier 3) will be equivalent to 3 or 4 P8 vehicles of the same power.

c. In terms of NOx, only generators with a power output of more than 56 kW (COP and Prime, Tier 4F) will be equivalent to 0.9 P8 vehicles. Generators with power below 56kW and all emergency generators (Tier 2 and Tier 3) will be equivalent to 8 to 14 P8 vehicles of the same power.

d. In terms of particulate matter, we have 3 categories to consider:

   - even COP and Prime generators with power greater than 56 kW (Tier 4F level) will be equivalent to 2 P8 vehicles of the same power.
   - all generators with power below 56 kW (Tier 2) will be equivalent to 40 to 80 P8 engines of the same power, which may represent a nuisance.
   - the other emergency generators (Tier 2 and Tier 3) will be equivalent to 20 to 40 P8 vehicles of the same power, which may represent a nuisance.

Briefly, the observations above can be better visualized in table 7 and indicate that the options for the Tier 2 and Tier 3 standards may require additional requirements in the licensing phase of fixed installations, where there is exposure of people.

Table 7 - Localized impact of a generator set on an equivalent number of P8 vehicles by category and proposed technological level

Pattern	Category	Engine power	CO	HC	Nox	PM
Tier 2	Everyone	kW<56	1.3 to 2.0	6	14	40 to 80
	Stand by	kW≥560	0,9	5	13	20
Tier 3	Stand by	56≤kW<560	0.9 to 1.3	3 to 4	8 to 9	20 to 40
Tier 4F	Prime/COP	kW>56	0.9 to 1.3	1,2	0,9	2,0

5. Conclusions

The proposal for an emission control program for generator sets has been discussed with manufacturers of emission control equipment and systems, government agencies and other AEA members who have participated in the Working Group, brings together various interests in a balanced manner and can be summarized as follows.

This program is not exactly aimed at reducing emissions from existing generators, but is intended to enable a realistic alternative so that new generators can be offered to the market in accordance with the best international emission standards. As a result, this program will stop the growth of emissions from the generator set park and offer the best solutions for correcting existing installations, where there are problems with the emissions of equipment, which can be replaced by a clean generator.

The state of the art, represented by the American Tier 4 Final standard (very close to the European Stage V) will be applied to the categories of generators that account for 87.5% of the energy produced by them. These are also generators with rated power above 56kW.

Conversely, all generators with power below 56kW, which account for only 6.1% of energy generation, will still meet Tier 2 standards, as they are low-cost machines with less environmental impact, although their emissions, expressed in g/kWh, are still much higher.

Finally, due to the high costs of Tier 4F technologies and the operational difficulties of aftertreatment systems for use in emergency generators, Tier 3 standards are proposed only for those with power between 56 and 560 kW, which are the most relevant and account for 5% of the energy generated, and the even higher ones remain as Tier 2 because they are of small production and account for only 1.4% of the total energy generated.

With this structure, the generator set emission control program will produce significant reductions in emissions, being greater than 90% for HC (pollutant associated with odor), NOx and PM, which are the main pollutants of Diesel engines.

From the individual aspect of an installation, all Tier 4F generators will have an impact similar to that of a truck of equal power, and are perfectly acceptable. In other cases, the generators will be equivalent to dozens of equivalent trucks working in the same place, especially with regard to particulates and NOx. This aspect will refer to the

installation to a specific licensing for each location, especially where there is exposure of people, when additional requirements may be made by the environmental agency, some of them commented below.

However, for generators with power below 56kW, this comparison is not very realistic, given the small size of the engine, and for generators with power above 56kW there will always be the possibility of meeting a specific requirement, such as choosing a Prime model, which will be available on the market in Tier 4F standards, although they require special operating procedures for intermittent operation. This possibility also applies to the replacement of generators in existing installations.

It is also important to note that for generators that will be used to supply electric vehicles, it will be necessary to implement state-of-the-art technologies, since the electrification of vehicles needs to rely on energy sources as clean as the most modern vehicle engines, which only occurs with Tier 4F standards.

6. Thanks

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