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Proposition of odor impact criteria and strategy for Brazil

Proposta de estratégia e critérios de avaliação de impacto causado pelo odor para aplicação no Brasil

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ABSTRACT The atmospheric pollution caused by odor emissions has become a relevant issue, but complex to regulate. The impact of an odor emission source can generally be characterized by the combination of the FIDOL factors (F – Frequency of occurrence; I - Intensity (odor concentration); D – Duration of each odor episode; O – Offensiveness; L – Location of source and receptor) , which must be addressed in a robust legislation. Since the legislation in Brazil related to environmental odors is scarce and subjective, the objective of this research is to suggest quantitative criteria for odor impact assessment, considering the Brazilian reality, as well as an assessment protocol, which form the strategy for odor assessment. The methodology was based on the analysis of data from international and Brazilian literature. The odor impact criteria suggested are dependent on the methods used for impact assessment. The criteria include: for field olfactometry, Concentration (C) <7 D/T ((*Dilution-to-Threshold ratio*); for dispersion modeling: C < 8 $ou_E.m^{-3}$ (residential/commercial areas) or C < 10 $ou_E.m^{-3}$ (other areas); 98th percentile, peak-to-mean ratio =1.821); use of good practice and the best available technique for control in the source, and minimum distance for new fugitive sources > 500m from residential areas. The assessment protocol is formed by four flowcharts which instruct the step-by-step for environmental licensing of odor emission sources, and odor complaint validation. It is expected that the adoption of clear and quantitative criteria for evaluating odor impact will enable the advancement of the prevention and solution of conflicts, besides contributing to a more harmonious coexistence between community and odor-emitting sources.

Keywords: odor pollution; odor impact criteria; FIDOL; olfactometry; environmental policy.

RESUMO A poluição atmosférica causada por emissões de odor tornou-se um problema relevante, porém complexo de se regulamentar. O impacto de uma fonte emissora de odor pode ser geralmente caracterizado através da combinação dos fatores FIDOL (F - Frequência de ocorrência; I - Intensidade (concentração do odor); D - Duração de cada episódio; O – Ofensividade; L – Localização da fonte e do receptor), os quais deveriam ser abordados para implementar legislações mais robustas. Visto que a legislação no Brasil relacionada a odores ambientais é escassa e subjetiva, o objetivo deste trabalho é propor critérios quantitativos de avaliação de impacto de odor, levando em conta a realidade brasileira, e um protocolo de avaliação, os quais compõem a estratégia de avaliação de odores. A metodologia se baseou na análise de dados da literatura internacional e brasileira. Os critérios de avaliação de impacto propostos são dependentes dos métodos utilizados para tal avaliação. Os critérios recomendados incluem: Para o método de olfatometria de campo: Concentração (C) <7 D/T (*Dilution-to-Threshold ratio*, ou razão de diluição); para modelagem de dispersão atmosférica: C < 8 $ou_E.m^{-3}$ (áreas residenciais/comerciais) ou C < 10 $ou_E.m^{-3}$ (outras áreas); percentil 98, Fator pico média =1,821; uso de boas práticas e das melhores tecnologias disponíveis para controle nas fontes emissoras de odor; e distância mínima de separação para fontes fugitivas novas: > 500 m de áreas residenciais. O protocolo de avaliação é composto por quatro fluxogramas, que instruem o passo a passo para o licenciamento ambiental de fontes emissoras de odor, e a verificação de reclamações. Espera-se que a adoção de critérios quantitativos e um protocolo claro para a avaliação do impacto relacionado ao odor possibilite avançar a prevenção e solução de conflitos, além de contribuir para uma convivência mais harmoniosa entre comunidades e fontes emissoras de odor.

Palavras-chave: poluição por odor; critérios de impacto de odor; FIDOL; olfatometria; política ambiental.

1. Introduction

Odor, generally caused by the mixture of odorous substances that interact with each other, producing a synergistic effect, is very relevant within the range of atmospheric pollution. The number of complaints that reach environmental agencies related to bad odor has grown, drawing attention to the importance of the topic (Malheiros *et al*., 2018; Conti *et al*., 2020). Unlike classic air pollutants, which are regulated by air quality standards of CONAMA Resolution 491/2018 (CONAMA, 2018), recently superseded by CONAMA Resolution 506/2024 (CONAMA, 2024), as for odor, Brazilian legislation is scarce, vague and subjective, which makes it difficult to solve the problem.

Five interrelated factors commonly referred to by the acronym FIDOL are widely accepted as important determinants of the impact of odors (Brancher *et al*., 2017): F - Frequency of occurrence; I - Intensity (odor concentration); D - Duration of each episode; O – Offensiveness; L – Location of source and receptor. Some European countries, such as Austria, Denmark, Norway have detailed legislation on the subject, addressing several or all of these factors (Brancher *et al*., 2017; Vieira, 2017).

As for the existing monitoring and impact assessment methods, some of the main ones are dynamic dilution olfactometry (DDO) according to EN 13725:2022 (CEN, 2022), field olfactometry (FO), field inspections with the grid method (CEN, 2016a) or plume method (CEN, 2016b), and atmospheric dispersion modeling (ADM) (Brancher *et al.*, 2017; Bax *et al.*, 2020).

In countries where there are no established criteria for odor impact assessment, arbitrary selection of criteria from other jurisdictions should be avoided. For example, it has been shown that ADM results can vary widely even for similar levels of protection (Brancher *et al.*, 2019). This implies that the reasoning behind the adoption of a specific criterion must be well discussed and justified.

Although notable progress has been seen recently, the assessment of odor impacts is still characterized by uncertainties and inherent gaps in assessment methods. These problems make it difficult to harmonize laws across jurisdictions and have contributed to the diversity of approaches and criteria related to environmental odor pollution.

Within this context, the objective of this work is to propose clear and objective quantitative criteria for assessing the impact of odor in Brazil, based on technical evidence and feasible to implement, as well as an assessment protocol to instruct the environmental licensing process of odor-emitting activities. These criteria and protocol form an odor impact assessment strategy, and are an innovation and an important tool for advancing the management of odor-related pollution in the country.

2. Methodology

This work deals with applied (practical) research. As for data analysis, due to its exploratory character, the research is classified as descriptive. As for the procedures, they were mainly based on bibliographical and documentary research for data collection. The international legal review was based on two articles which present an in-depth analysis of international legislation: Brancher *et al.* (2017), who studied 28 countries, and Bokowa *et al.* (2021), which covered 17 countries. While Brancher *et al.* (2017) focused on ADM-specific odor impact criteria (OIC), Bokowa *et al.* (2021) reviewed and summarized odor legislation in a broader context. In addition, an evaluation of studies produced in Brazil on the impact of odors was carried out, in which the aspects of methodology and evaluation criteria adopted were organized in tables.

At this stage, in view of the scarcity of national research papers, works published in scientific events, journal articles, monographs, dissertations and thesis were included. The searches were carried out on the Scielo database, on the website of the Institutional Repository of the Federal University of Santa Catarina (UFSC), a pioneer institution on the study of odors in Brazil, on the São Paulo University (USP) School of Public Health, and on the Superior School of the Environmental Protection Agency of São Paulo (CETESB). The initial year was established as 2014. In total, 6 Brazilian works were evaluated, which already reveals the awakening of the topic in Brazil, and shows the need for this present work in order to move forward.

Considering the information from international legislation and Brazilian studies, odor impact criteria (OIC) were developed for application in Brazil, whose justifications are presented in the discussion of results.

3. Results and discussion

This research suggests a multi-tool strategy for odor assessment consisting of three categories, adapted from Bull *et al.* (2014); Vieira (2017); and Brancher *et al.* (2017): 1) Predictive: atmospheric dispersion modeling; 2) Observational/Empirical: monitoring of odor in the environment; 3) Mitigation and control: minimization and control of odor impact risks; use of Best Available Techniques (BAT), management plans and good operational practices; proactive measures at sources.

According to Vieira (2017), the concentration of ambient odor can be classified according to three thresholds: perception (1 $ou_E.m^{-3}$ – European odor unit per cubic meter); recognition (1 – 5 $ou_E.m^{-3}$); and nuisance (5-10 $ou_E.m^{-3}$). In addition to concentration (measurement of factor I – Intensity of FIDOL), international odor impact criteria generally also include a percentile value (P) (to assess the factor Frequency of FIDOL) and the definition of time interval for mean calculation, or peak-to-mean ratio (F) (to evaluate the factor D – Duration). Table 1 presents a summary of the criteria found in the countries studied by Bokowa et *al.* (2021) and Brancher *et al.* (2017).

Below, criteria for the field olfactometry (FO) method and for atmospheric dispersion modeling (performed based on emission rate data obtained with DDO and/or FO) are presented.

3.1. Impact Criteria for Field Olfactometry (FO)

According to Brancher *et al.* (2017), field olfactometry (FO) is the most employed technique in North American jurisdictions to assess levels of odor pollution. In general terms, this technique consists in the use of a portable field olfactometer to provide the dilution of odorous air with clean odorless air, in discrete and known ratios. The result is given in terms of D/T (Dilution-to-Threshold ratios), namely the number of dilutions needed to cause the odor to become imperceptible, which enables the quantification of odor concentration (St. Croix Sensory Inc, 2020). The application of the

TABLE 1 – Summary of odor impact criteria (OIC) in 28 countries: percentiles (P), threshold odor concentration (Ct), peak-to-mean ratio (F).

Evaluated countries	28 countries - South Africa, Germany, Saudi Arabia, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, South Korea, Denmark, Spain, USA, France, Hong Kong, Hungary, Ireland, Israel, Italy, Japan, Norway, New Zealand, Netherlands, Panama, United Kingdom, Taiwan.	
FIDOL factors	OIC - Odor Impact Criteria	
Frequency	Percentiles (P)	85-100
Intensity	Threshold odor concentration (Ct)	0.25 - 35 or_E/m^3
Duration	Averaging time	1s - 1h
	Peak-mean ratio (F)	1 - 45

SOURCE: Adapted from Brancher *et al.* (2017) and Bokowa *et al.* (2021).

FO is practical and requires less time and resources compared to more robust methodologies. However, the author warns that a well-defined and standardized procedure is essential to ensure reliable results for the technique. Disagreements may arise if the FO is randomly applied. Measurements are *quasi* momentary and are, therefore, governed by meteorological conditions and the emission time profile of the odor source at the time of measurement.

Table 2 lists the odor limits established by legislation in various United States of America (USA) jurisdictions, based on the FO method.

According to Table 2, the legislative approach used in the USA generally requires that odors do not cause nuisance outside the boundaries of the emitting source property, a nuisance verified by field inspectors, in response to complaints. The definition of nuisance occurs, in most cases, with results of odor concentration ≥ 7 D/T (Connecticut, 2006; North Dakota, 2007; Colorado, 2013; Missouri, 2014; Kentucky, 2016; Vieira, 2017; Wyoming, 2018). Most of these legislations require that at least two assessments be carried out within the period of one hour, with an interval of at least 15 minutes between them, and these must be carried out on the property boundary of the source, or on the sensitive receptor (complainant), by trained inspectors.

The limit of 7 D/T corresponds exactly to the proposed criterion for application in Brazil, as the desirable level. This criterion has already been adopted in several studies with field olfactometry carried out in Brazil (Malheiros *et al*., 2016; Malheiros *et al.,* 2018; Perazzoli *et al*., 2018; Schraier *et al*., 2019), and are compatible with Vieira's classification (2017) already cited.

Therefore, in summary, the odor evaluation criteria suggested for application in Brazil, considering the FO method for verifying complaints, are presented in Table 3.

3.1.1. Monitoring program

In the USA, in general the use of legislation requiring FO is initiated by complaints, and it is assumed that these already include the Frequency, Duration and Offensiveness factors of FIDOL. This leaves only the Intensity to be confirmed by the environmental agency inspector; if necessary, the inspector can also confirm the character and offensiveness of the odor to be sure that the correct enterprise is being investigated (McGinley, 2022). In general, field inspections to confirm complaints are brief, lasting an hour or two (McGinley, 2022).

However, field olfactometry can be used for purposes other than checking complaints, for example: for routine operation monitoring of activities with potential for odorous emissions; for odor diagnosis studies which aim to identify and prioritize odor sources, for evaluating the effectiveness of odor control measures, for verifying and calibrating odor dispersion models, among other objectives (St. Croix Sensory, 2020). For these broader purposes, it is necessary to develop an adequate monitoring plan for each specific case. This item seeks to present some minimum guidelines, based on studies already carried out in Brazil (Table 4), on recommendations from the manufacturer of one of the commercial models of field olfactometer (McGinley, 2018; McGinley, 2022), and on the guidelines of the field inspection standards by the grid and plume method (EN 15841-1 and 2) (CEN, 2016a; CEN, 2016b).

TABLE 2 – Ambient air odor thresholds using field olfactometry – USA.

Political state or subdivision	Odor concentration (D/T)			
	Residential	Commercial	Industrial	Other areas (not expressly listed)
Colorado	<7	<7	<15	<15
Connecticut	<7	<7	<7	<7
Illinois	<8	<8	<24	<16
Kentucky	<7	<7	<7	<7
Missouri	<7	<7	<7	<7
North Dakota	<7	<7	<7	<7
Nevada	8	8	8	8
Oregon	–	–	2	–
Wyoming	<7	<7	<7	<7
District of Columbia	1	1	1	1
Dallas, Texas	2	1	1	1
Southwest Washington State (AQMA)	1-2	1-2	8-32	-
Polk County, Iowa	7	7	7	-
Cedar Rapids, Iowa	4	8	20	-
Omaha, Nebraska	4	8	20	-
Chattanooga, Hamilton County, Tennessee	0	4	4	-

SOURCE: Adapted from McGinley, Mahin & Pope (2000) e Mahin (2001) apud Vieira (2017); Colorado (2013); Connecticut (2006); Illinois (1993); Kentucky (2016); Missouri (2014); Nevada (2022); North Dakota (2007); Wyoming (2018).

TABLE 3 – Criteria for evaluating odor in ambient air (imission) based on field olfactometry to verify complaints, suggested for application in Brazil.

Criteria	Odor concentration (D/T)	Form of evaluation for verification of complaints
Desirable Level	<7	At least two assessments within the period of one hour, with an interval of at least 15 minutes between them, to be performed on the sensitive receiver (complainant), by trained inspectors.
Level of Potential Nuisance e	≥7	

SOURCE: The authors.

The monitoring plan is a matter of specific professional assessment on a case-by-case basis. Aspects of quantity and location of complainants, the possibility of legal action, available resources, and other aspects must be considered to define the ideal monitoring plan. The most common is the selection of 10 to 30 points around the company or activity to be evaluated, and visit these points. For periodic or routine monitoring, all points, or just selected points, can be considered based on wind condition (points downstream of the expected odor plume) (McGinley, 2018; McGinley, 2022).

If the objective of monitoring with FO is validation of dispersion modeling studies, it is recommended to perform more than one sampling at multiple points, trying to capture different meteorological conditions, or even trying to represent the critical meteorological condition (McGinley, 2018; McGinley, 2022).

As for the number of odor panelists, Brandt *et al.* (2011) determined that for complex cases of legal disputes, the ideal would be evaluations with 4 assessors. But according to McGinley (2018; 2022), this is not feasible for most situations; in the USA, the most common situation is only one assessor. Conducting simultaneous monitoring with two panelists periodically can be an alternative to show that multiple assessors have similar results (McGinley, 2018; McGinley, 2022).

In addition, other aspects that can be considered when preparing a monitoring plan are related to:

(i) type and characteristics of emitting sources,
(ii) temporal variability of emissions,
(iii) complainant points and
(iv) monitoring route and its measurement locations.

More details on each of these aspects can be found in Perazzoli (2022).

Table 4 presents the compilation of monitoring plans applied to field olfactometry in the studies carried out in Brazil, analyzed in this research.

Table 5 presents a suggestion of minimum requirements to be considered in FO monitoring plans in Brazil, for case studies of odor diagnosis and for environmental license compliance verification (routine monitoring).

3.2. Impact Criteria for Atmospheric Dispersion Modeling (ADM)

Bearing in mind that currently there is no quantitative standard for the immission of odor in Brazil, the pioneer legislation should define a criterion that is easy to understand and to apply. Is should also be balanced: not excessively restrictive or permissive. Periodically, this legislation may be reviewed, incorporating more details and suggesting more restrictive limits, as the criteria's use experience advances in the country.

Criteria are suggested for two types of area (zones): residential/commercial, which are areas that generally have a higher population density and where nuisances tend to occur more frequently, because of sensitivity; and agricultural, industrial and other unspecified areas, whose use is less sensitive and in general have lower population density, therefore, where slightly less restrictive limits can be accepted.

In relation to odor offensiveness be subjected to regulation, it should be pointed out that the concepts of "offensive" and "pleasant" odor are not absolute, and different individuals react distinctly

TABLE 4 – Comparison of field olfactometry (FO) monitoring plans for Brazilian studies.

Reference	Source type studied	FO Monitoring Plan	Human Resources	Other necessary resources	Field collection time
Malheiros *et al.* (2014)	Industrial complex with 3 food industries and WWTP	84 samples	1 trained evaluator and 1 field assistant	Field olfactometer, portable weather station	5 days
Malheiros *et al.* (2016)	Agroindustrial swine slaughter plant and its WWTP	29 points, about 100 samples at different times	2 trained people	Field olfactometer, portable weather station	4 days
Perazzoli *et al.* (2018)	Municipal WWTP (anaerobic lagoons)	23 points, total of 68 samplings during 6 days.	1 trained evaluator and 1 field assistant	Field olfactometer, portable weather station	6 days
Malheiros *et al.* (2018)	Industry in the state of Paraná	6 points around the industry, covered in a monthly campaign, at different times and on different days over 18 months (total of 108 samples).	1 trained evaluator and 1 field assistant	Field olfactometer, portable weather station	Monthly visits of about 2 hours for 18 months
Schraier *et al.* (2019)	Municipal WWTP	19 external and 10 internal points, 131 samples. Distances from 250 to 300m covering an area of 2 km	1 trained evaluator and 1 field assistant	Field olfactometer, portable weather station	5 days

SOURCE: The Authors.

TABLE 5 – Suggestion of minimum requirements for field olfactometry (FO) monitoring plans, for application in Brazil.

Type of study	FO Monitoring Plan	Human Resources	Other necessary resources	Field collection time
Criteria for diagnostic studies	Each measurement cycle must contain at least 40 samples (Guillot *et al.*, 2012; Silva, 2020), distributed in 10 to 30 points (McGinley, 2018; McGinley, 2022).	At least 1 trained evaluator. If possible, a field assistant accompanying the evaluator, or a second evaluator	Field olfactometer, portable weather station	Minimum duration of 3 days (if there are no complaints) or 4 days (if there are complaints), covering different times, including at least from 07:00 to 19:00.
Criteria for routine monitoring	5 to 10 points on the sensitive receptors closest to the sources			Monthly visits, with measurement cycles of at least 1 hour at pre-established points, alternating hours to cover different periods of the day.

SOURCE: The authors.

TABLE 6 – Criteria for assessing odor in ambient air (imission) for atmospheric dispersion modeling (ADM) used in Brazilian studies.

Reference	Source type	Odor evaluation criteria		
		Concentration (ou_E/m^3)	Percentile	Averaging time and F
Malheiros *et al.* (2016)	Swine slaughter plant and its WWTP	<8 6	99 98	3 min F = 1.821
Telles (2018)	Brewing industry (point and area sources in the WWTP).	5	98	1h F = 1
Perazzoli *et al.* (2018)	Municipal WWTP (anaerobic lagoons)	<8	99	3 min F = 1.821
Schraier *et al.* (2019)	Animal by-products processing industry (Rendering)	5	98	1h F = 1

SOURCE: Adapted from Malheiros *et al.* (2016), Telles (2018), Perazzoli *et al.* (2018) e Schraier *et al.* (2019).

to the same odor. Nonetheless, some odors are recognized as offensive for the general population. For this reason, Initially, only offensive odors need to be regulated, given that pleasant odors are less likely to raise complaints about discomfort, which is confirmed by the compilation of Brazilian scientific studies (Table 4 and Table 6), since all studies assessed sources of odor considered unpleasant. Table 10 of item 3.4 of this article lists the priority activities for applying the proposed assessment protocol, which emit odor admitted as offensive. Table 6 presents the summary of quantitative odor evaluation criteria used for ADM in the Brazilian studies evaluated in this research. All studies used the AERMOD regulatory model, which is a gaussian and steady-state atmospheric dispersion modeling system. Just as other models, it uses emission data from sources, together with topographic and meteorological data, to simulate the pollutant concentration in the study area.

On the other side, Table 7 presents the compilation of evaluation criteria adopted by different countries for ADM, based on the work of Brancher *et al.* (2017) and Bokowa *et al.* (2021). The Table shows that the most frequently adopted percentile is P98, and that 42% of the countries studied have different criteria for different land uses (Location factor).

When comparing FO results (Table 3) and modeling, the frequency and intensity criteria adopted in both methods should be as uniform as possible to produce consistent results. The definitions of D/T (field olfactometry) and $ou_E.m^{-3}$ (ADM using DDO data) units are quite similar, as shown by equations (1) (St. Croix Sensory Inc, 2020) and (2) (McGinley, 2018; Malheiros *et al.*, 2018):

$$C_{odor}\left[\frac{D}{T}\right] = \frac{\text{Volume of filtered air (no odor)}}{\text{Volume of ar with odor}} = \frac{V_{filtered}}{V_{odor}} \quad (1)$$

$$C_{odor}[ou_E.m^{-3}] = \frac{\text{Total volume of air}}{\text{Volume of ar with odor}} = \frac{V_{filtered} + V_{odor}}{V_{odor}} = \frac{V_{filtered}}{V_{odor}} + 1 \quad (2)$$

TABLE 7 – Ambient air odor (imission) assessment criteria for atmospheric dispersion modeling (ADM) used in 24 countries.

FIDOL factors	OIC - Odor Impact Criteria		# countries	% of countries	Countries that adopt this criterion
Frequency	Percentiles - % (P)	85≤ P ≤97	2	8%	Germany and Austria
		P=98	10	42%	Italy, France, Ireland, Netherlands, United Kingdom, Spain, Colombia, Germany, Belgium, Canada
		99 ≤ P < 100	8	33%	Australia, Denmark, Norway, Israel, Italy, France, Netherlands, Canada
		P = 100	4	17%	Israel, Hong Kong, Italy, Canada
Intensity	Odor threshold concentration - ou_E/m^3 (Ct)	0.25 - 35 $ou_E.m^{-3}$	23	96%	Canadian, US and Australian jurisdictions; Chile, Colombia, Panama, United Kingdom, Germany, Austria, Lombardy (Italy), Puglia (Italy), Ireland, Netherlands, Israel, Taiwan, Hong Kong, South Korea, China, Japan, Hungary, Belgian jurisdictions, Catalonia (Spain), Denmark, France
Duration	Average time (T) and Peak-average ratio (F)	equal to 1 hour (F = 1)	11	46%	Australia (Queensland), NZ, Denmark, Norway, France, Ireland, Netherlands, United Kingdom, Spain, Colombia, Belgium
		Other than 1h (1s, 5s, 1, 3, 4, 10 min) (F ranges from 1.65 to 45)	8	33%	Australia (NSW, South Australia, Victoria, Western Australia); Austria, Denmark, Israel, Hong Kong, Italy, Germany, Canada
Offensiveness	Offensive Adjustment	Different types of activities have different Ct or P;	6	25%	Netherlands, United Kingdom, Spain, Colombia, Panama, Belgium
Location	Location Adjustment (land use)	Ct varies according to the surrounding population density	1	4%	Provinces of NSW and South Australia (Australia)
		Different types of land use have different Ct or P according to sensitivity	10	42%	NZ, Austria, Denmark, Norway, Israel, Apulia(Italy), Netherlands, Germany, Belgium, Canada
Differentiation between existing and new ventures (more restrictive criteria)			6	25%	Israel, Italy, France, Netherlands, Belgium, Canada
Total			**24**		

SOURCE: Adapted from Brancher *et al*. (2017) and Bokowa *et al*. (2021).

In this way, it is possible to compare the FO results, in D/T, and the estimated concentration for the surroundings by the ADM with DDO results, in $ou_E.m^{-3}$, as follows (adapted from Malheiros *et al.*, 2018):

$$C_{odor-ADM}[ou_E.m^{-3}] = C_{odor-FO}\left[\frac{D}{T}\right] + 1 \quad (3)$$

Regarding the percentiles, the author Griffiths (2014) suggests the use of a calibrated multipercentile criterion, which has, in theory, the potential to more accurately predict the extent of annoyance caused by odor than single percentile criteria, when tested in a wide range of exposures. Other cited advantages include full range evaluation of impacts, from chronic to acute; ability to predict cumulative impact contributions from multiple sources with different temporal emission profiles (intermittent to constant); and potential for improved prediction and analysis of meteorological conditions, periods of day and times of year which are most problematic for odor impact (Griffiths, 2014). However, the author himself points out that even this type of multipercentile criterion may have limitations to take into account the nuisance resulting from the frequency and intensity dimensions of odor.

Therefore, considering the current Brazilian reality, in which there is no quantitative criterion of odor impact, it is suggested that a single percentile criterion will be a great advance for odor management and impact minimization, without requiring such in-depth technical knowledge from stakeholders, as would be needed to apply the multipercentile criterion.

The 98th percentile (2% probability of exceedance) provides sufficient protection, while allowing an “exception” for infrequent situations of bad weather (occurring less than 2% of the time, i.e. less than one week per year). In this way, the odor impact criterion avoids exposure to high concentration odors over long periods (high frequency). Minimizing the frequency of exposure through P98 protects against the chronic effects of community exposure to odor. The use of relatively low percentiles such as the P98, instead of a higher percentile such as the 99.5 (applied for example in the province of Queensland, Australia) prevents secondary factors, such as the temperature of the exhaust gases from the emission sources, from excessively influencing the results (Brancher *et al.*, 2019).

One should keep it in mind that even if this criterion is put into effect, effects related to acute exposures may still possibly occur, but because the frequency of exposure is low, negative effects may only occur if the odor concentration of the episode is relatively higher.

Regarding the averaging time in defining Odor Impact Criteria (OIC), the ratio between the short-term average value (relevant for odor perception) and the long-term average (predicted by the dispersion model), called the *peak-to-mean* factor, is widely used to describe fluctuations, despite its notable limitations. The response time of the human olfactory sense to a stimulus is in the order of seconds, characterizing a non-linear and instantaneous perception. For this reason, in odor impact assessment studies, peak concentrations are very important (Brancher *et al.*, 2020). Several factors have been used, resulting in average times of varying from 1 second to 1 hour (Brancher *et al*., 2017). The two main approaches of OIC with regard to average time are, according to Table 7 and Brancher *et al.* (2017):

a) Hourly-based criteria (in which short-term perception is possibly empirically incorporated), therefore it is not necessary to apply a peak-to-mean factor, and whose advantage is the simplicity of application;

b) Criteria that incorporate some consideration to reflect the biology of the human nose, i.e. exposure in short periods of time (minutes or seconds), which is the most recommended approach (Brancher *et al*., 2017). This approach has several variants, from the use of a constant peak-to-mean factor, to the calculation of variable factors in time and space (Griffiths, 2014; Brancher *et al*., 2020).

The study by Brancher *et al.* (2020) evaluated three selected approaches to predict sub-hourly concentrations of peak odor concentration, namely:

1 – constant peak-to-mean factor equal to 4;

2 – variable peak-to-mean factor according to atmospheric stability and distance from the source; and

3 – calculation of the variable peak-to-mean factor taking into account the variance of the concentration at each point.

Approach 1 is the simplest, and 3 is the most complex. The conclusion was that the accuracy and adequacy of the peak-mean factors is directly proportional to the complexity of the approach. Approach 3 (concentration variance) had the best result, with a slight tendency to overestimate. Approach 1 (constant factor equal to 4) overestimated all observations, and approach 2 greatly underestimated the results (Brancher *et al*., 2020).

Bearing in mind the status of the topic in Brazil, it is suggested that initially the adoption of a constant peak-to-mean factor be adopted, due to the convenience of implementing and verifying it, and because it is a conservative approach, since a tendency to overestimate the values has been shown (Brancher *et al*., 2020), provided that a sufficient factor is adopted.

According to Simms *et al.* (2000) apud Vieira (2017), the average time of 3 minutes is adequate to represent the short-term detection capacity of human smell, since the odor needs to be detectable for a sufficiently long time to become a nuisance. This time interval is also suitable for the FO method (Malheiros *et al*., 2018). Applying the power law for a peak time of 3 min and exponent n = 0.2, results in F = 1.821, as used in other studies (Table 6). Therefore, the odor evaluation criteria for the ADM method suggested for application in Brazil are summarized in Table 8.

Note that the suggestion in Table 8 is aligned with the principle already applied to noise assessment limits in communities, from standard NBR 10.151: 2019, which are more restrictive for more sensitive land uses, such as residential areas, and less restrictive for less sensitive uses, such as industrial areas (ABNT, 2019).

TABLE 8 – Criteria for assessing ambient air odor (imission) for modeling atmospheric dispersion, suggested for application in Brazil.

Zone	Odor concentration (ou_E/m^3)	Percentile	Average time (F)	Way of Evaluation
Residential / Commercial	<8	P98	3 min (F= 1.821)	Criterion should be evaluated at the nearest sensitive receptor. Dispersion model and its settings must be accepted by the environmental agency (AERMOD or CALPUFF), using a minimum of 3 years of hourly representative meteorological data. For existing sources, emission rate must be calculated based on dynamic olfactometry sampling (EN13725), or if it is not possible to use this method (for example, for fugitive sources), perform reverse modeling with field olfactometry data, according to specific guidelines of Table 5. For planned sources, perform DDO on similar sources and if this is not possible, use suitable emission factors.
Agricultural, industrial or other unspecified areas	<10			

SOURCE: The authors.

3.3. BAT Criteria and Minimum Distances from Population Centers

According to Perazzoli (2022), about 80% of Brazilian legislation related to odor requires the control of odorous emissions at emitting sources or the use of BAT (best available techniques). Therefore, a proposal for an odor evaluation criterion should take into account this perspective of the emission sources, and not just the surroundings. It is suggested, therefore, that the criteria for the Brazilian legislation include an obligation (or, at the very least, a recommendation) for the application of BAT for new odor sources to be implemented, in order to prevent/mitigate high odor emissions to the surroundings, and even avoid the need for more in-depth studies such as dispersion modeling, field evaluation, etc.

In turn, the recommendation of minimum separation distances, especially for activities that cause fugitive odorous emissions (for example, animal husbandry, application of animal manure to the soil (fertirrigation), sanitary landfills, composting, waste water treatment plants, among other non-conducted sources) is another effective legal criterion to prevent nuisances and contribute to a better land use management.

In this way, it is suggested that minimum separation distances of 500m be required between new activities with fugitive odor emission and residential areas (existing or planned), following the recommendation of *TA Luft*, German regulation (GMBI, 2021).

Smaller distances may be admitted, provided that the following conditions are met simultaneously: implementation of specific odor control or treatment systems; carrying out of ADM studies that prove compliance with the odor impact assessment criteria (Table 8) before the project's construction, duly approved by the licensing agency; and that during the enterprise's operation, monitoring campaigns are carried out with field olfactometry, which confirm compliance with the desired level of Table 3.

Table 9 summarizes the legal criteria for assessing environmental odor developed in this research, bringing together three regulatory approaches cited by Brancher *et al.* (2017) and detailing the types of sources (new or existing), the methodologies applied, the proposed criteria and the form of evaluation for each criterion. It includes the criteria detailed in Table 3 and Table 8.

3.4 Assessment protocols for practical criteria application in environmental licensing

The challenge for regulatory bodies is to provide protection for the community from nuisance odors, without unfairly disadvantaging odor-emitting activities that are generally necessary for the economic maintenance of the community itself. Achieving this balanced goal requires the use of a range of strategies and approaches, depending on whether the activity is new or already existing, as well as the complexity of its sources (MeloLisboa *et al.* 2014). Seeking to overcome this challenge, this study proposes the following protocol for assessing odor in different cases.

Brancher et al. (2017) agrees with previous regulatory review work (Rwdi Air Inc, 2005; DEFRA, 2010; Bull *et al.*, 2014) that relevant elements of regulatory assessment frameworks are:

1. impact assessment of new developments or expansions: predictive tools such as dispersion modeling and comparison with OIC, and fixed or variable separation distances are among the few tools available;

2. impact assessment of existing developments: observational and empirical data indicate whether there is an odor problem; for example, analysis of complaints, community surveys and field studies such as inspections or field olfactometry;

3. Mitigation and control plans: the tools to support the industry in order to minimize and manage the risks of odor impact once the activities start operating: use of Best Available Technology (BAT) for treatment and control of emissions; odor emission limits and robust and proactive odor management plans, which include actions for odor treatment and/or elimination.

It should be clarified that category 1 tools are not the most suitable for category2, and category 2 tools are not available for use in new enterprises, and have a different purpose. Therefore, the use of multiple tools is an indicator of a mature and effective regulatory framework (Brancher *et al.*, 2017).

Based on the discussion already presented and the impact assessment flowcharts suggested by Vieira (2017), as well as considering the criteria of Table 9, four flowcharts were developed to form the assessment protocol proposed in this study: prior licensing and/or installation (in Portuguese, equivalent to licenciamento prévio - LP e/ou de instalação - LI) of new emitting sources (Figure 1); renewal of operating license (in Portuguese, equivalent to Licença de Operação - LO) for existing sources, when there is no previous record of odor complaints (Figure 2); renewal of operating license

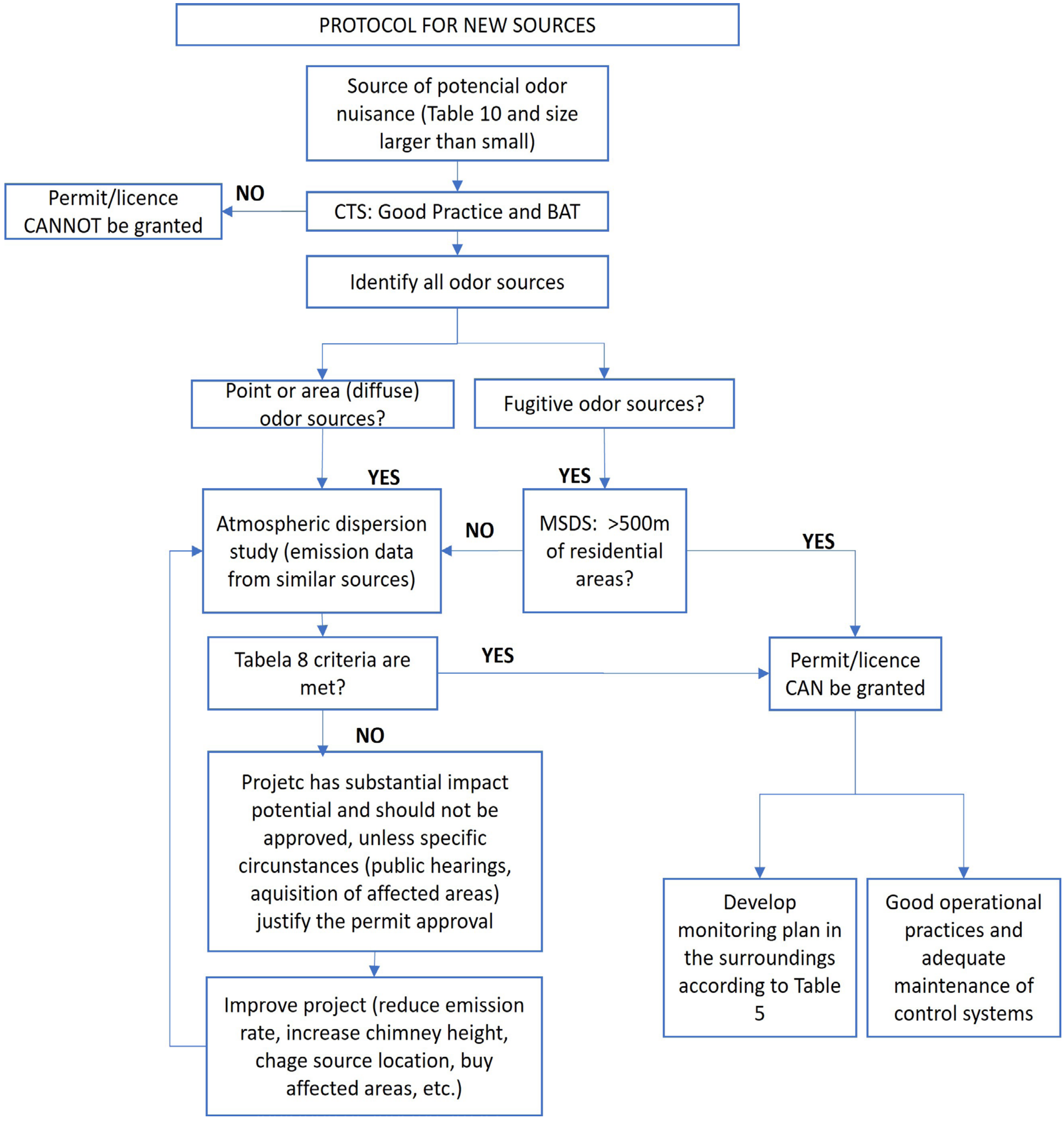

FIGURE 1 – Evaluation flowchart for licensing of new odor emission sources.
SOURCE: The authors.

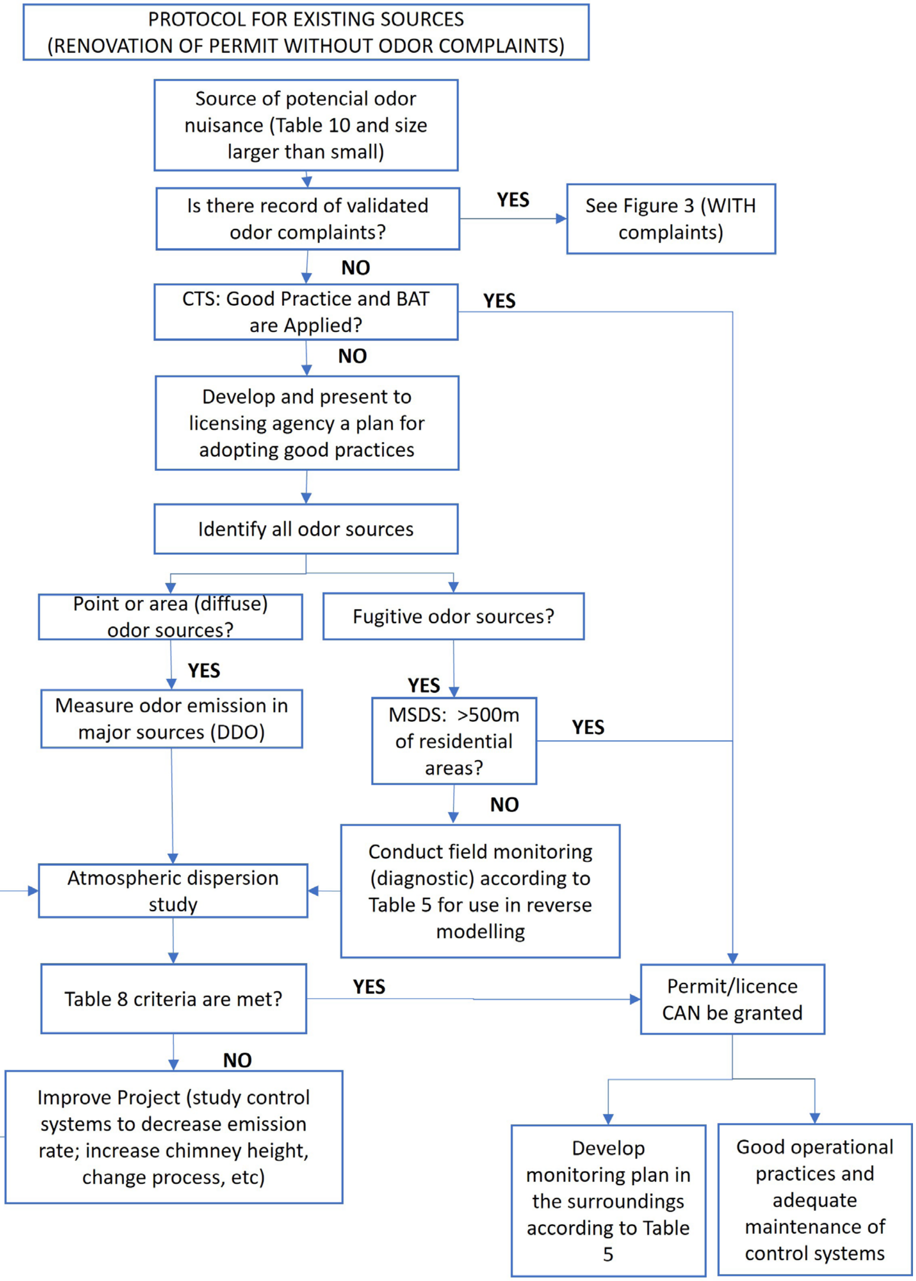

FIGURE 2 – Evaluation flowchart for licensing existing odor emission sources (renewal) without odor complaints.
SOURCE: The authors.

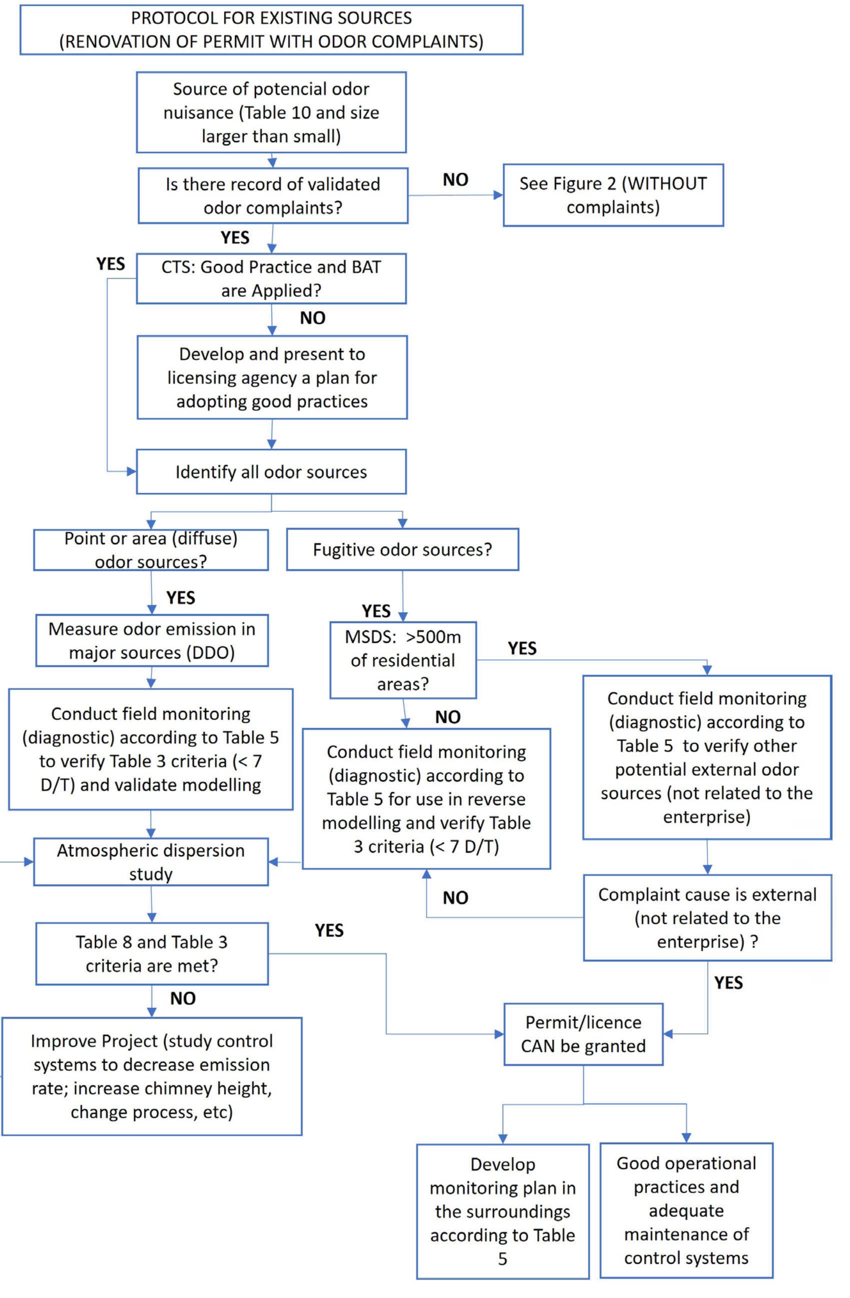

FIGURE 3 – Evaluation flowchart for licensing existing odor emission sources (renewal) with odor complaints.
SOURCE: The authors.

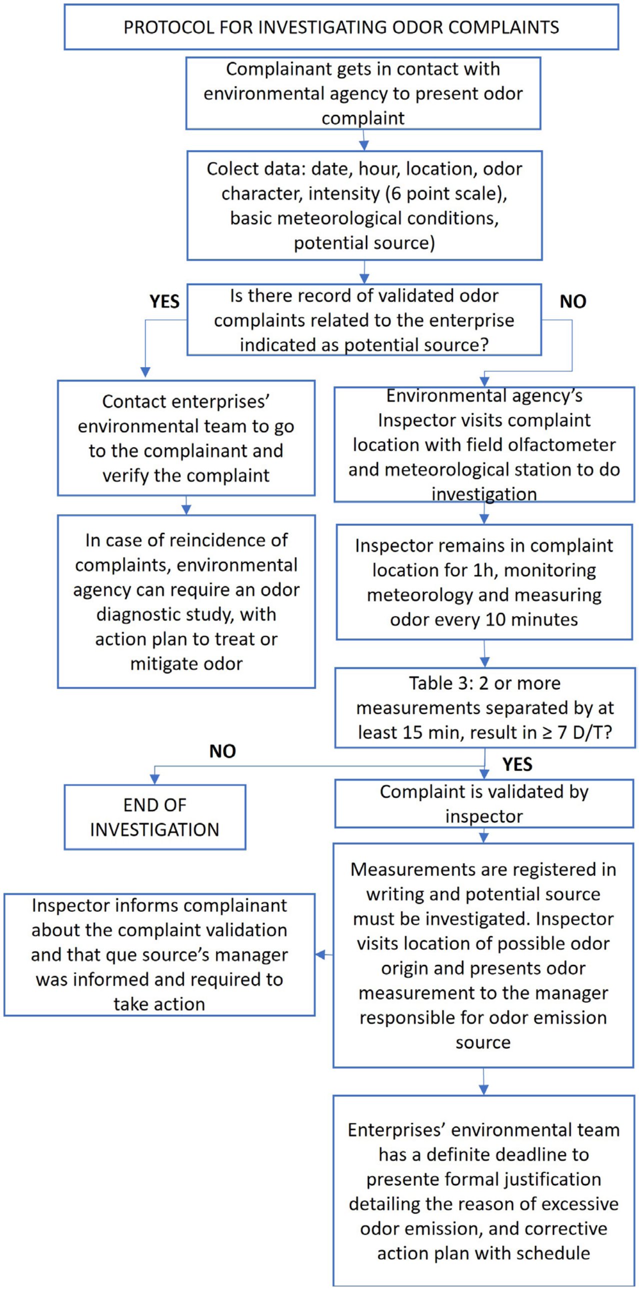

FIGURE 4 – Flowchart for investigating odor complaints (complaint validation).
SOURCE: The authors .

TABLE 9 – Summary of legal criteria for environmental odor assessment suggested for application in Brazil.

Regulatory Approach	Source type	Methodology	Proposed Criterion	Way of Evaluation
Maximum Impact Standard (MIS)	New and existing	Atmospheric Dispersion modeling (ADM)	Table 8 (C < 8 ou_E m ^{3} (residential/ commercial) or < 10 ou_E m^{-3} (other areas); P98, F=1.821)	Table 8
		Field olfactometry (FO)	Table 3 (<7 D/T)	Table 5 (diagnostic studies or routine monitoring)
Control Technology Standard (CTS)	New and existing	Not applicable	Requirement to use best operational practices to prevent and/or minimize odor emissions	New sources: operational plan informing which best practices to be applied; Existing Sources: Periodic photographic reports demonstrating evidence of best practices, presented to the environmental agency as part of the license requirements.
	New	Not applicable	Requirement to use BAT for all new odor sources to be implemented	
Minimum Separation Distance Standard (MSDS)	New	Not applicable	500m between new activities with fugitive emissions and existing or planned residential areas. Smaller distances may be allowed, provided that adequate control systems are installed and compliance with the criteria in Table 8 (dispersion modeling) and Table 3(field olfactometry) is demonstrated.	Studies and projects to be presented by the entrepreneur in the licensing process.

SOURCE: The authors.

for existing sources, when there is a previous record of odor complaints (Figure 3); and a flowchart for verifying odor complaints (Figure 4).

The sources for which we suggest applying this protocol are those linked to theactivities listed in Table 10.

The size of the enterprise or activity must be classified as larger than small, according to the environmental licensing legislation in force in the state in which the source is located. Thus, small enterprises are, in general, exempt from the application of this protocol, which allows the environmental agency's efforts to be directed towards enterprises with a greater potential for impact, i.e. those of medium, large or exceptional size. This does not exclude the possibility of the environmental agency applying the protocol to specific small sources, if they prove to be relevant from the point of view of impact on the surroundings, according to the agency's assessment.

Figure 1 shows the evaluation flowchart suggested for licensing newsources with odor emission potential, in the stages of issuing a Preliminary License (LP) and/or Installation License (LI). It is clear that the first criterion to be applied is the Control Technology Standard, i.e. good operating practices and the use of BAT(Best Available techniques), which aims to prevent and minimize the risk of odor generation directly at the planning stage of the project. Without the implementationof good practices and BAT, the license cannot be granted.

The next step is to identify the sources of odor and classify them as point or diffuse (which must be assessed by dispersion modeling) or fugitive, for which the minimum distance criterion from existing or planned population centers (> 500m) must also be applied. If this distance is not met, the permit can only be granted if dispersion modeling is carried out and the odor impact criteria (Table 8**)** are met. If the criteria are exceeded, the project must be returned to the planning stage and adjustments made until the criteria are met.

The license or permit can be granted when the criteria are met. Next, an odor monitoring plan must be developed following the criteria in Table 5 for routine monitoring, and good operating practices and proper maintenance of control systems must be implemented to ensure long-term impact prevention.

Figure 2 shows the flowchart for renewing a license/permit for existing sources, when there is no previous record of odor complaints. Initially, it is checked whether good operating practices are being used and whether the BAT for odor control are employed. If so, considering the absence of complaints, the license can be renewed without additional studies. If not, it is necessary to present a plan for adopting good practices, as well as identifying all existing sources of odor. If they are fugitive, there is need to check the minimum distance; if they are point or diffuse, there is need to carry out emission

TABLE 10 – Examples of activities and sources of odor and the most common classes of odorous substances.

Family	**Substances /parameters**	**Examples of activities and/or sources with odor emission potential**
Reduced sulfur compounds	Hydrogen sulphide (H_2S), mercaptans, methylsulphide, Total Reduced Sulphur (TRS), etc.	Municipal and industrial wastewater treatment plants (mainly anaerobic treatment), pulp and paper industry; biodigesters, composting, landfills, tanneries, etc.
Nitrogen compounds	Ammonia (NH_3),Methylamines, etc.	Meat processing plants, rendering plants, landfills, slurries and their treatment systems, animal farms, oil refineries, intensive animal husbandry, composting, agricultural activities, etc.
Volatile Organic Compounds (VOCs)	Phenol, Formaldehyde, Acetaldehyde, Acetic Acid, Acetone, etc.	Landfills, municipal and industrial sewage treatmentplants, slaughterhouses, animal by-product factories, food industries, farms, roasting and cooling of coffee, peanuts, cashew nuts, barley; drying kilns for painted parts; asphalt oxidation; meat smoking; rubber regeneration; oil refineries; foundries, petrochemical parks,intensive animal husbandry.

Source: Adapted from São Paulo (1978); SEMA (2014); Zarra *et al.* (2008); Brancher *et al.* (2017).

measurements with DDO and dispersion modeling to check the criteria listed in Table 8.

Figure 3 shows the flowchart for permit renewal cases when there is a historical recordof odor complaints. The difference between this flowchart and Figure 2 is the inclusionof field monitoring (field olfactometry in the surroundings) for diagnosis and verificationof compliance with the < 7 D/T criterion (Table 3).This monitoring may also be necessary to verify cases in which the source of the odor causing the complaint is not the activity under evaluation, especially if it only has fugitive sources and meets the criterion for minimum distance from population centers. Field olfactometry data can also be used to support reverse dispersion modeling in the case of fugitive sources that cannot be adequately assessed by DDO.

The license or permit can be renewed if it is confirmed that the cause of the complaints isexternal to the enterprise, or if the evaluation criteria are met. Even after the license has been issued, management and monitoring actions must continue, with the implementation of the odor monitoring plan in the surroundings and the collection of evidence of the application of good operating practices and adequate maintenance of odor control systems.

Finally, Figure 4 shows the flowchart to be followed by the environmental agency for validating complaints (i.e. investigating odor complaints). Data on the odor episode should be collected and recorded in a database for future reference. If there havealready been complaints validated by the environmental agency for the same odor- generating enterprise, the environmental agency inspector notifies the enterprise's team to verify the complaint, thus saving the environmental agency's team time, which is only responsible for the first validation of each enterprise's complaint.

In this case, the trained inspector visits the location of complaint as soon as possible after the complaint, equipped with a field olfactometer and portable meteorological station, and remains on site for an hour taking measurements every 10 minutes. He then checks if the Table 3 criterion (< 7 D/T) is met. If not, the investigation procedure ends and the inspection record is archived. If not, the complaint is validated and the potential odor source must be visited by the inspector, preferably immediately after the complaint has been validated, informing the responsible team, who must provide a justification and action plan within a timeframe set by the agency.

It should be noted that in order to aid the success of complaint investigation, the communities surrounding odor emissions sources must be adequately informed of how to report complaints, through a communication plan that disseminate contact channels, and also there must be accountability for the actions taken.

Conclusions

The analysis of international legislation related to ambient odor showed that in the researched universe, 85% of the countries use an Odor Impact Criterion (OIC) composed of an odor concentration value, a percentile value and a peak-to-mean factor value, and that this OIC is evaluated using atmospheric dispersion modeling. The survey and systematization of odor impact assessment studies carried out in Brazil showed that the FO, DDO and ADM methods are already being used in the country. Whereas criteria adopted in other jurisdictions must be adjusted to the Brazilian reality, odor impact criteria were proposed for Brazil, contemplating the methods of field olfactometry - FO (desirable level < 7 D/T) and atmospheric dispersion modeling - ADM (C < 8 $ou_{E.}$ m^{-3} (residential/commercial) or < 10 $ou_{E.}$ m^{-3} (other areas); P98, F=1.821). For fugitive new sources, a minimum separation distance of 500 m for existing or planned residential areas has been proposed. For existing and new sources, it is suggested that best operational practices be required to minimize odor emissions, as well as the use of BAT for new sources.

An assessment protocol was also proposed, which is formed by four flowcharts, in order to provide orientation about the practical application of OIC in the environmental licensing process. This protocol and criteria aim the formalization and standardization of procedures, bringing clarity to all involved stakeholders.

These criteria and the protocol form a strategy for odor impact assessment in Brazil, and are an innovation and an important tool for advancing the management of odor-related pollution in Brazil. Hopefully, the adoption of these well-defined criteria and methods will help to prevent and solve conflicts and contribute to a harmonious coexistence.

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