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Review

Summary and Overview of the Odour Regulations Worldwide

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Abstract: When it comes to air pollution complaints, odours are often the most significant contributor. Sources of odour emissions range from natural to anthropogenic. Mitigation of odour can be challenging, multifaceted, site-specific, and is often confounded by its complexity—defined by existing (or non-existing) environmental laws, public ordinances, and socio-economic considerations. The objective of this paper is to review and summarise odour legislation in selected European countries (France, Germany, Austria, Hungary, the UK, Spain, the Netherlands, Italy, Belgium), North America (the USA and Canada), and South America (Chile and Colombia), as well as Oceania (Australia and New Zealand) and Asia (Japan, China). Many countries have incorporated odour controls into their legislation. However, odour-related assessment criteria tend to be highly variable between countries, individual states, provinces, and even counties and towns. Legislation ranges from (1) no specific mention in environmental legislation that regulates pollutants which are known to have an odour impact to (2) extensive details about odour source testing, odour dispersion modelling, ambient odour monitoring, (3) setback distances, (4) process operations, and (5) odour control technologies and procedures. Agricultural operations are one specific source of odour emissions in rural and suburban areas and a model example of such complexities. Management of agricultural odour emissions is important because of the dense consolidation of animal feeding operations and the advance of housing development into rural areas. Overall, there is a need for continued survey, review, development, and adjustment of odour legislation that considers sustainable development, environmental stewardship, and socio-economic realities, all of which are amenable to a just, site-specific, and sector-specific application.

Keywords: odour legislation; air quality; air pollution; odor; smell; odour units; dispersion modelling; agriculture; environmental regulations; policy

1. Introduction

This paper is a collaborative work by seventeen international odour experts sharing comprehensive summaries and evaluations of odour policy and legislation from seventeen countries/regions: Europe (Austria, Belgium, France, Germany, Hungary, Italy, the Netherlands, Spain, the UK), Asia (China, including Hong Kong, Japan), Australasia (Australia, New Zealand), North America (the USA, Canada), and South America (Chile, Colombia).

While the authors acknowledge that this paper is only a snapshot in time of current worldwide odour policy, the content of the paper will always maintain historical value (i.e., the status of odour regulatory approaches as of 2019) and will likely remain relevant as a gauge for changes made to regulations in the future and which tend to evolve slowly.

Odour issues are currently one of the major causes of environmental grievances around the world and, in some countries, are routinely the cause of most environmental complaints to regulatory authorities. There continue to be multiple reasons for the prominence of odour complaints, including an unrelenting urban expansion of residential areas into land use areas once predominantly agricultural with few largely isolated facilities; increases in facility operations and their size; increasingly higher aesthetic, environmental expectations of citizens, who are less familiar and tolerant of odours than in the past; and concerns over potential health risks from airborne odourous substances.

In most countries, environmental legislation covers most types of common air pollutants, and there is little variation between jurisdictions with such legislation. However, odour legislation tends to be much more varied and varies across a wide spectrum: from having little to no specific mentioning in environmental legislation to extensive and rigid detailing in odour source testing, odour dispersion modelling, ambient odour monitoring, setback distances, process operations, and odour control procedures. Odour legislation can be highly variable from one jurisdiction to the next.

Odour issues are very complex, and, therefore, an excellent understanding of the formation of odour released into the atmosphere and exposure is important. The exposure of individuals living in odour-prone areas may lead to immediate annoyance, which in the long term may lead to it being defined as a nuisance. In some countries, odour policies are based solely on odour nuisance criteria, and so the question arises on how to determine odour nuisance. There are several guidelines for nuisance such as use and loss of enjoyment of the property, interference with the normal conduct of business, damage to animal and plant life, human health and safety, or property damage. Some countries, provinces, or states have also defined odour concentrations at which the odour nuisance could occur, taking into consideration several factors such as frequency and duration of odour episodes. Therefore, a common use of the FIDOL factors (frequency, intensity, duration, offensiveness, and location/receptor) is often used by some jurisdictions to determine the likelihood of odour annoyance in the area.

Nuisance can also be determined based on the validity of odour complaints and odour measurements. The odour measurements are either performed at the sources [1,2] or at locations where odour may be present by conducting direct odour monitoring [3,4]. Measurements conducted at the sources include estimating odour emission rates at each potential odour source in $ou_E \cdot s^{-1}$ and the use of dispersion modelling to establish odour concentrations (in ou or in some countries recorded as in $ou_E \cdot m^{-3}$) at sensitive receptors, at the property line, or at any other affected areas. Some countries set the limit for odour, either based on dispersion modelling criteria at the nearest sensitive receptor, or property boundary (for example, in New Zealand and some states of Australia (Tasmania), or in certain Canadian provinces such as Ontario province), or based on direct odour monitoring at the affected areas (for example, in Germany and some American states). The limits are either called the odour impact criteria (OIC) or odour concentration or detection thresholds. The OIC are based on odour concentrations and the accepted probability of exceeding the concentration (i.e., percentile) to define compliance. In some countries where there is no odour control, the odour limit may be determined by some specific and relatively easy-to-measure compounds such as hydrogen sulfide or ammonia. In some European countries such as France, odour exposure limits are also set as emission limit values (ELV) in $ou_E \cdot s^{-1}$ or $ou_E \cdot h^{-1}$. On the other hand, in several U.S. states, the dilution-to-threshold (D/T) field olfactometry approach is used to set the limits.

Odour nuisance depends on various predictors of odour, which are often summarised with the acronym FIDO (frequency, intensity, duration, and offensiveness), with factors not presented in any prioritised order [5]. In New Zealand and Australia, a fifth factor, "L", as in FIDOL, refers to the odour location [6]. This additional factor refers to the sensitivity of the surrounding residential area. For example, odours near a school may increase concerns for citizens.

Almost all odour policies specify criteria or otherwise reference the intensity component of FIDO: either through a measure of odour concentration as odour units per cubic metre ($ou_E \cdot m^{-3}$) from laboratory olfactometry [1]; as an odour index threshold value through the triangle bag method; as perceived odour intensity [7,8]; or as offensiveness [9] (or as D/T) through field olfactometry measurements [10].

The frequency and duration of odour episodes are often taken into consideration through dispersion modelling of odour emission rates to determine odour exposure to receptors and the number of hours in a year with odours present. The OIC limit the number of odour hours or provide a requirement for per cent of the hours in a year without odours (e.g., 98%). Secondly, frequency and duration are assessed through field inspection and documentation of the odours present.

In any investigation of odours, the character of the offending odours is documented to identify their source. Some policies have different criteria or even different approaches for specific odour sources.

Currently, odour policies are highly variable between countries, individual states or provinces, and even between counties and towns. These policies include (1) no specific mention in environmental legislation, (2) regulation of pollutants which are known to have an odour impact, (3) consideration of odour perception as a nuisance, (4) setting standards for specific odourants or other contaminants such as hydrogen sulfide; and (5) extensive detail for odour assessments, including odour source testing, dispersion modelling, ambient odour monitoring, setback distances, process operations, and odour control technologies and procedures, and (6) other approaches. While there are differences in the details of these policies, all policies outlined in this paper include one or more of these FIDO factors of odour nuisance. This paper outlines these varying approaches and discusses the advantages and disadvantages of the systems.

2. Europe—A Common Approach

In twenty-eight (28) European Union countries, odour is regulated through the Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions—in short, the Industrial Emission Directive or IED. The IED establishes a general framework for determining limits, including odour limits for many industrial activities/processes intending to (among others) control odour emissions.

The covered sectors include, for example, the energy industry, metals production and processing, waste management, chemical and mineral industry, and agriculture sectors such as animal production.

A complete list of sectors can be found in Annex 1 of the IED.

This European IED rules that installations should operate only if they hold a written permit or, in certain cases, if they are just registered. The permit conditions are defined to achieve a high level of protection for the entire environment. These conditions are commonly based on the concept of the best available technique (BAT). To determine BATs and limit imbalances in the EU with regard to the level of emissions from industrial activities, reference documents for BAT (named BREF) are drawn up [11].

There are over 30 BAT reference (BREF) documents published, which are related to different sectors. The new BREF documents also include the new figure of best available technology associated emission levels (BAT AELs), defining a range for the emission limits for any installation pursuing a permit [12]. As of 2019, the only BREF in Europe that set an odour limit is the recently published Waste Treatment BREF that establishes a range of 200 to 1000 $ou_E \cdot m^{-3}$ as the maximum allowed odour concentration for some BATs related to the biological treatment of waste [11].

It is important to note that BREFs are neither prescriptive nor exhaustive. The BREFs do not consider local conditions, so their application does not relieve the countries' permitting authorities from an obligation to make site-specific judgments. That means that during the permitting procedure, the responsible authority has to take into consideration all information provided by the BREF, including the operator's application and the local conditions to set an odour limit.

Some other legally binding documents and guidelines related to odours are available in a few European countries. Those odour regulations are used when no specific criteria are set in a BREF, or when the IED does not cover the odour-emitting activity.

Specific odour regulations and policies in France, Germany, Austria, Hungary, the United Kingdom, Spain, the Netherlands, Italy, and Belgium are introduced below.

2.1. France

France has an overall odour regulation based on the IED for any activity included in this regulation. In addition, France has specific regulations regarding odour control for two special activities: animal by-product processing plants and composting plants. Further, there are some common emission limit values (ELV) for the food and beverage processing industry.

2.1.1. Animal by-Product Processing Plants

The order from 12 February 2003 related to animal by-product processing plants is still in force despite several revisions [13]. Article 28 of that order lists different, relevant OIC, depending on the facility status. For a new plant, the OIC are set to 5 $ou_E \cdot m^{-3}$ in a radius of 3 km from the fence of the installation less than 44 h per year (99.5th percentile). This calculation is based on emission factors.

For an existing plant, the OIC are set to 5 $ou_E \cdot m^{-3}$ in a radius of 3 km from the fence of the installation less than 175 h per year (98th percentile). This calculation has to be made from on-site odour measurements, followed by air dispersion modelling. If dispersion modelling is not performed, the odour concentration should not exceed 1000 $ou_E \cdot m^{-3}$ for any source, no matter the stack height. However, if there are any odour complaints, the inspector may require an odour dispersion modelling or may ask for an increase in the frequency of odour measurements.

According to point 10 of the same order, if the odour concentration at the existing plant stack exceeds an ELV of 100,000 $ou_E \cdot m^{-3}$, then an olfactometric measurement according to the EN 13725 [1] must be performed every three months (Table 1). The frequency of the odour concentration measurement can be reduced to once per year if the plant is equipped with a representative and permanent electronic sensing device.

Table 1. Frequency of odour concentration checks for animal by-products processing plants [13].

Odour Concentration ($ou_E \cdot m^{-3}$)	**Frequency of Odour Concentration Checks**	**Frequency of Odour Concentration Checks (with an Electronic-Sensor)**
>100,000	quarterly	annual
5000–100,000	biannual	biennial
<5000	annual	triennial

If the plant's odour concentration is between 5000 and 100,000 $ou_E \cdot m^{-3}$, then an olfactometric measurement must be performed every six months according to the EN 13725 [1]. This measurement frequency can be reduced to once every two years if the plant has an electronic sensor for an odour monitoring system installed. If the odour concentration at the plant is less than 5000 $ou_E \cdot m^{-3}$, then an olfactometric measurement according to the EN 13725 must be performed every year. This measurement frequency could be reduced to once every three years if the plant has an electronic sensor for an odour monitoring system installed.

2.1.2. Composting Plants

The order of 22 April 2008 related to composting plants is currently in force despite several revisions [14,15]. According to Article 26, there are different OIC regulating composting plants. For both existing plants and new plants, the OIC are set to 5 $ou_E \cdot m^{-3}$ in a radius of 3 km from the fence of the installation less than 175 h per year (98th percentile). This calculation has to be made from on-site odour measurements in the case of existing plants and based on estimations in the case of new plants. In the case of existing plants, all the odour sources should be identified. If the sum of all the odour emissions is less than 20,000,000 $ou_E \cdot h^{-1}$ or if the plant is located in an area with a low risk of odour impact, there is no need to do anything else. If any of these two criteria are not met, an odour dispersion model should be performed in order to verify that the existing plant complies with the OIC of 5 $ou_E \cdot m^{-3}$ in a radius of 3 km from the fence of the installation less than 175 h per year (98th percentile). If the OIC are exceeded, the existing plant has to send an Odour Management Plan to reduce its impact to meet the previously outlined criteria.

2.1.3. Food and Beverage Industries

In the case of the food and beverage industry, there are some odour ELVs in $ou_E.h^{-1}$ which depend on the emission point's height according to the following (Table 2):

Table 2. Odour emission limit values (ELVs) for food and beverage industries [16–18].

Height of Point Source Emission (m)	Odour Emission Limit ($ou_E \cdot h^{-1}$)
0	1000×10^3
5	3600×10^3
10	$21,000 \times 10^3$
20	$180,000 \times 10^3$
30	$720,000 \times 10^3$
50	3600×10^6
80	$18,000 \times 10^6$
100	$36,000 \times 10^6$

One of the main points about the legislation regarding the food and beverage industry is that the minimum stack height is fixed and it is a function of the odour emission limits. These limits were previously mentioned for other industries, but it was often a better choice to treat the effluent and decrease the emitted concentration than to build very high stacks.

2.2. Germany

According to § 3 (1) of the Federal Immission Control Act [19], harmful effects on the environment are caused by many substances present in ambient air. According to their nature, extent or duration, they are liable to cause hazards, considerable disadvantages, or considerable nuisance to the general public or the neighbourhood. In the case of odours, the type of ambient odour is considered by the description of the smell, and the ambient odour extent or level is quantified by odour detection above the recognition threshold and uses the concept of the odour hour. The duration is expressed by the odour frequency (odour hours per year). If the odour frequency exceeds the specific exposure limit values given in the German Guideline on Odour in Ambient Air (GOAA) [20], the odour exposure is classified as a "considerable nuisance" according to the BImSchG [19].

In Germany, odour regulation for livestock farms and industrial installations has a long-lasting history. After several attempts to regulate odour exposure, e.g., by setback distances for livestock farms and industrial installations, a concept based on odour frequencies as detailed in the first GOAA in 1993 was developed. The GOAA was developed further in 2008, considering odour intensity, hedonic tone, and annoyance potential of specific odours [20]. The concept given in Figure 1 has been approved in many cases and is generally accepted at court. This concept has the outstanding advantage that the results of grid measurements and dispersion modelling can be directly compared because both methods aim to determine recognisable odours in terms of odour frequencies.

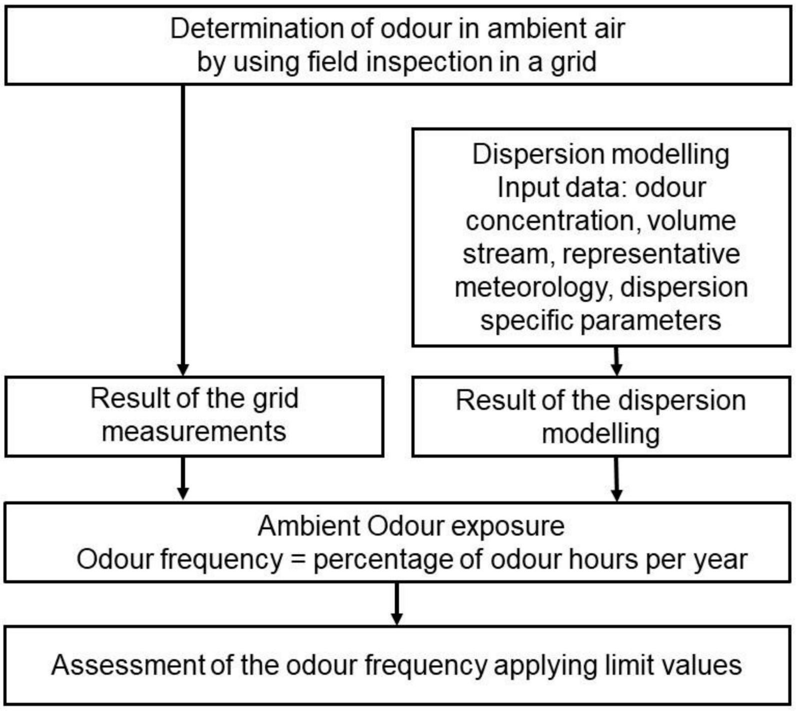

Figure 1. The concept of the GOAA [21].

Determination of odour in ambient air by using field inspections in a grid has to be conducted according to guideline VDI 3940-1:2006 [22]. However, in 2017, EN 16841 Part 1 [3] superseded this guideline. This method allows the standardised measurement of recognisable odours (in terms of odour hours) in the field by panel members. An odour hour is obtained when the percentage odour time of a single measurement reaches or exceeds 10% by convention. It is a statistical survey, which considers different times of the day, week, and year (for details, see EN 16841 Part 1) [3]. The grid method is the only method to determine the perceived odour in the field over periods of six months or a whole year. Therefore, the method is mainly applied in cases of complaints in the neighbourhood of odour sources or for determining the odour frequency. The disadvantage of this method is, among others, that the duration of the survey (at least six months) and that the representativeness of the results depend on the meteorology and the emission variation during that time interval.

Dispersion modelling with either the measured or estimated odour emission is the method that is used in most of the cases in Germany. The Lagrangian dispersion model AUSTAL2000G (G (Geruch) stands for odour) is used to calculate odour frequencies. In the

AUSTAL2000G model, the spread of the particles in the atmosphere is simulated depending on the wind speed and direction. The mean odourant concentration is calculated as the average hourly value. If the average hourly value is above an assessment threshold of cthr = 0.25 $ou_E \cdot m^{-3}$, the relevant hour is counted as an odour hour [23]. On this basis, the annual mean odour hour frequency is calculated [23]. For odour emission measurements, EN 13725:2003 [1] is applied in combination with guideline VDI 3880:2011 [2] on static sampling and VDI 3884-1:2015 [24] with supplementary instructions for application of EN 13725 [1].

One of the disadvantages of dispersion modelling is that the input data (Figure 1) are often vague. Odour emissions cannot be quantified sufficiently for some sources, such as diffuse sources or area sources. Additionally, the representativeness of the meteorology for the location is often limited. Looking at court cases, the recoverable claim is that the results of the calculation of odour frequencies by dispersion modelling have to be conservative. If they are compared with grid measurement results as a measure for the existing odour frequency, they need to be at least equal or higher [25].

Finally, the odour hour frequency is assessed by applying limit values. These limit values are the outcome of several investigations where the odour frequency was correlated with the annoyance degree of residents (e.g., [26,27]). The limit values expressed as relative odour frequencies per year are 0.10 (10%) for residential and mixed areas, 0.15 (15%) for commercial and industrial areas, and 0.15 (15%) only for livestock odours in villages with a mixture of houses and farms.

Another finding of these investigations was the lower annoyance potential of clearly pleasant odours [28]. A definition of clearly pleasant odours is given by the GOAA as well as the method. The method to be applied is the polarity profile method [29]. For clearly pleasant odours, a weighting factor of f = 0.5 can be used before applying the limit value.

In an investigation, especially on livestock farming, the odour frequency caused by cattle, pigs, and poultry was correlated with the annoyance degree of residents. A lower annoyance potential was found for dairy cows, including young cattle (f = 0.5), and for fattening pigs and sows (f = 0.75), whereas a higher annoyance potential was found for poultry (f = 1.5). Investigations in 2017 [30] combining plume measurements according to VDI 3940-2:2006 [31] (superseded by EN 16841–2:2017 [4]) and the polarity profile method showed a lower annoyance potential for horses and fattening bulls (f = 0.5). A follow-up study in 2019 showed similar results for sheep and nanny goats [32].

In practice, the GOAA is used by responsible authorities all over Germany. It is applied in the licensing and surveillance of installations, in cases of odour complaints, and in urban land use planning. The measurements are carried out by accredited laboratories based on the standards EN 13725 [1] and EN 16841 Part 1 [3] (former VDI 3940–1:2006 [22]). Currently, it is planned to include the GOAA in the Technical Instructions on Air Quality Control [33], which would further increase their legal bindingness for local authorities.

2.3. Austria

Austria's regulations distinguish between limit values that have a legal basis and guiding or target values, which are only part of guidelines without a legal basis. In general, there are no legal limit values for odours in Austria. For spa areas [34], a target value for the exceedance probability p_T = 3% for an odour concentration of C_T = 1 $ou_E \cdot m^{-3}$ (similar to Germany) is suggested. The Austrian Academy of Sciences published a guideline (without legal relevance) with two limit values (both have to be taken into account to fulfil the criteria) [35]. The odour concentration threshold C_T is only given verbally as odour intensity:

- An exceedance probability of p_T = 8% for a "weak" odour intensity;
- An exceedance probability of p_T = 3% for a "strong" odour intensity.

To apply these two limit values for dispersion modelling, the verbally given odour intensity needs to be converted to odour concentration. For the "weak" intensity, an odour concentration of $C_T = 1\ ou_E{\cdot}m^{-3}$ is used, and for the "strong" intensity, an odour concentration in the range $ou_E{\cdot}m^{-3} < C_T < 8\ ou_E{\cdot}m^{-3}$ is used.

The local government of Styria issued a guideline [36], which suggests new odour impact criteria taking into account the annoyance potential (hedonic tone) for four categories, characterised by typical odour sources: (1) small (e.g., biofilter, silage, horses, sheep, goat), (2) medium (brewery oil mill, domestic fuel, pig), (3) high (e.g., bitumen, refinery, kitchen, poultry), and (4) very high (e.g., nauseating smell, tannery, composting facility, some parts of wastewater treatment plants). For continuous emitting sources, the exceedance probability p_T (%) of the guideline is related to the German odour hour definition, which means the odour concentration threshold is $C_T = 1\ ou_E{\cdot}m^{-3}$ (Table 3). For discontinuous emitting sources, the OIC are defined by a certain exceedance probability of $p_T = 2\%$ and an odour concentration C_T (Table 4).

Table 3. Odour impact criteria (OIC) based on the guideline of the local government of Styria, Austria, for continuous sources [36], defined by a certain threshold concentration of $C_T = 1\ ou_E\ m^{-3}$ and the exceedance frequency p_T (%).

Annoyance Potential	Exceedance Probability p_T (%)	Exceedance Probability p_T (%)
	Non-Livestock Sources	Livestock Sources (Pure Residential Areas/Agricultural Dominated Villages/Other Utilization)
Small	40	40/50/-
Medium	15	15/20/30
High	10	10/15/20
Very high	2	-/-/-

Table 4. Odour impact criteria (OIC) based on the guideline of the local government of Styria, Austria, for discontinuous sources [36], defined by a certain exceedance probability of $p_T = 2\%$ and the threshold concentration C_T.

Annoyance Potential	Threshold Concentration C_T ($ou_E{\cdot}m^{-3}$)	Threshold Concentration C_T ($ou_E{\cdot}m^{-3}$)
	Non-Livestock Sources	Livestock Sources (Pure Residential Areas/Agricultural Dominated Villages/Other Utilization)
Small	15	15/20/-
Medium	5	5/7/10
High	4	4/5/7
Very high	1	-/-/-

This odour interval is related to short-term concentrations to mimic the odour perception of the human nose [37]. In summary, Austria uses a variable peak-to-mean (the relevant short-term peak odour concentrations are calculated with a stability-dependent peak-to-mean algorithm) approach [38,39], but in many cases, the German peak-to-mean factor (F) equal to 4 is used as a constant value [40]. Therefore, the concentration for a 1 h mean value of $C_T{*} = 0.25\ ou_E{\cdot}m^{-3}$ is used. A new approach to calculating the short-term odour concentration based on one-hour mean values is used beside the two other methods. The "concentration variance" method [41] was implemented in the Lagrangian dispersion models GRAL and LASAT [42,43]. A critical review of the three methods can be found in Brancher et al. (2020) [42].

Austria also has a guideline related to livestock buildings (guideline for the evaluation of ambient odour emitted by livestock buildings [44]) that offers two alternatives to evaluate the emission of farm animals. The first alternative uses a qualitative comparison of the odour emission rate, the impact of the ventilation system on the emission characteristics, and the local conditions at the livestock farm. This results in a dimensionless odour number, which is then used to assess if this farm size is common in this area. The second alternative is the application of a dispersion model, where an empirical equation is derived to simplify the calculation of the separation distance [45]. In the Austrian guideline, the

German GOAA [20] and the Austrian Academy of Sciences [35] are mentioned for odour impact criteria, which can be selected to assess odour annoyance and calculate separation distances.

2.4. Hungary

Hungary does not have legal national odour impact criteria in use. However, to avoid any odour annoyance, it is suggested that the exceedance probability (pT) = 2% (98th Percentile) is used for an odour concentration threshold range of 3 $ou_E \cdot m^{-3} < C_T < 5$ $ou_E \cdot m^{-3}$ [46].

2.5. United Kingdom

The regulators are slightly different in the four countries, England, Wales, Northern Ireland, and Scotland, which make up the United Kingdom, but the regulations are substantially the same.

Numerous individual local authorities and four environment agencies are responsible for regulating the impact of odourous emissions from industrial and commercial premises in England, Wales, Scotland, and Northern Ireland [47]. Waste activities, larger industrial processes, and intensive livestock farms are regulated by the environment agencies under the IPPC directive through Environmental Permitting Regulations (EPR), and smaller enterprises, as well as those below the size thresholds for the EPR, are regulated by local authorities. Local authorities use three regimes for odour control: (i) planning, (ii) permitting (which is similar to the EPR requirements discussed below), and (iii) statutory nuisance.

Local authorities regulate and approve planning applications for all premises and, for those that may generate odours, may impose planning conditions to help control emissions. Planning authorities may ask for evidence of the extent of the process's odour impact when considering applications, but this is far from universal and may take the form of a comparison with an existing process or a dispersion model based on new or existing odour emission rates. Planning controls are generally less robust on smaller businesses, such as food take-aways and restaurants, than larger concerns such as intensive livestock farms. There is considerable variation in the levels of control exercised by different authorities in different council areas.

Where odour modelling is used, the local authority planning departments may assess the predicted impact of the process against benchmark criteria that have been agreed upon or previously used in other planning cases. An example of the potential criteria, based on the Environment Agency (EA) H4 Horizontal Guidance [48], is shown in Table 5 below.

Table 5. Odour impact criteria based on Environment Agency (EA) guidance [48].

Offensiveness Scale	OIC	Example of Odour Sources
Most offensive odours	1.5 $ou_E \cdot m^{-3}$	Decaying animal or fish remains, septic effluent or sludge, biological landfill odours
Moderately offensive odours	3 $ou_E \cdot m^{-3}$	Intensive livestock rearing, fat frying (food processing), sugar beet processing, well-aerated green waste composting
Less offensive odours	6 $ou_E \cdot m^{-3}$	Brewery, confectionery, coffee roasting, bakery

These benchmarks may be used to support evidence submitted with a planning application or with a permit application. They are based on the annual 98th percentile of hourly average concentrations of odour modelled over 3 to 5 years at sensitive receptor locations.

These benchmarks are considered when determining setback distances from existing operations and levels of abatement that may be required for existing operations. Some councils sometimes impose lower odour concentration values.

2.5.1. Assessing Odour Impacts for Planning Purposes

The Institute of Air Quality Management has issued a guidance on the assessment of odour for planning and a guidance on interpreting dispersion modelling, which also includes methodologies for field odour studies and desk-study risk-based assessments [49]. The risk assessment methodology includes consideration of the source odour potential, pathway effectiveness, predicted odour exposure, and receptor sensitivity to qualitatively determine the magnitude of the odour effects at the specific receptor location odour effects, ranging from negligible impact, through slight adverse impact and moderate adverse impact, and up to substantial adverse impact. This methodology is quite dependent on the judgment/discretion of the assessor.

2.5.2. How Odours Are Assessed to Be Qualified as a Nuisance

If there are complaints of odours from non-EPR premises, the local authority environmental health department officers have a statutory duty to investigate the complaints [50]. To determine if odours constitute a statutory nuisance, local authorities can consider one or more of the following: where the odour is coming from, the character of the area, the number of people affected nearby, if the odour interferes with the quality of life of people nearby (for example, if they avoid using their gardens), how often the odour is present, and the characteristics of the odour [51]. Councils usually use at least two officers to confirm a nuisance.

For the odour to be determined a statutory nuisance, it must do one of the following: unreasonably and substantially interfere with the use or enjoyment of a home or other premises, injure health, or be likely to injure health.

The operator or premises have the potential to demonstrate that they are using best practicable means (BPM) as a defence [52]. The enforcement officers (usually designated Environmental Health Officers) should be objective and thorough in their investigation [47]. If the odourous process operator does not apply BPM to abate the odourous emissions, then an "Abatement Notice" is issued for the enforcement of the statutory nuisance, and legal proceedings will then apply. If the operator has used BPM to stop or reduce the odour, they may be able to use this as one of the grounds for appeal against the abatement notice or as a defence. If no appeal is made, then the Abatement Notice stands, and the operator can be prosecuted for not complying with the abatement notice in the criminal courts, although the BPM defence is also available in these circumstances.

Statutory nuisance laws do not apply to odours arising from residential properties, but they do apply to odours from business premises affecting residential properties.

2.5.3. Processes and Premises Regulated by the Environment Agencies under the EPR

The bodies responsible for regulating the industrial and farming activities not covered by the local authorities are Natural Resources Wales (NRW), the Scottish Environmental Protection Agency (SEPA) for Scotland, the Northern Ireland Environment Agency (NIEA) for Northern Ireland, and the Environment Agency (EA) for England [53–57].

The environment agencies use a permitting system to regulate the impact of the emissions. Concerning processes likely to causes odours, there is usually a condition within the permit setting out a requirement such as "the activities shall be free from odour at levels likely to cause pollution outside the site, as perceived by an authorised officer of the Environment Agency, unless the operator has used appropriate measures, including, but not limited to, those specified in any approved odour management plan, to prevent or where that is not practicable to minimise the odour. The operator shall submit to the Environment Agency for approval an odour management plan, which identifies and minimises the risks of pollution from odour; and they shall implement the approved odour management plan." [55].

Appropriate measures are normally assumed to include best available techniques (BAT) with BAT based on factors including best practice in the industry sector and relevant guidance, including European BREF [52] guidance for specific industry sectors. If an operator fails to comply with the terms of the permit, and in particular with their odour management plan, then a series of actions is taken by the environment agencies, ultimately leading to a withdrawal of the permit and prosecution.

In summary, the environment agencies set out their approach with the result in the following scenarios:

1. Where no odour is detectable or likely to be detectable, there will be no pollution beyond the boundary of the site concerning odour pollution.
2. Where odour is detectable, it may or may not cause offence, and the agency response will depend upon the degree of pollution and the cost and practicability of any remedial measures.
3. Where all appropriate measures are being used but are not completely preventing odour pollution, a level of residual odour will have to be accepted.
4. Where the odour is serious, even if all efforts have been made to apply BAT/appropriate measures, it may be necessary to suspend or revoke the permit in full or in part.

Normally, the process of enforcement leading ultimately to permit suspension or revocation will involve the regulator (the EA, SEPA, NRW, or NIEA) serving the operator with improvement or enforcement notices with the objectives of improving odour control management. Similar benchmarks to those used by local authorities are considered when determining setback distances from existing operations and levels of odour mitigation or abatement that may be required for existing operations and proposed new installations.

2.6. Spain

Spain also has an overall odour regulation based on the IED for any activity included in this regulation. The Law 5/2013 [58] and the Royal Decree 8/15/2013 [59] made the transposition of the European IED. The competences of the IED lie in the autonomous communities (AC). As a general approach, the procedure is to set ambient air odour limits for industrial activities, which are based on the following steps:

- The facility/activity (new or existing) applies to obtain a permit.
- The environmental administration evaluates if there is an odour concern and, if necessary, an odour assessment is requested.
- There is no guideline for decision making on odour assessments results. The outcome completely depends on the environmental officer assigned to the case.
- Upon completion of an odour assessment (if performed), the individual OIC are set by the environmental officer, which are typically based on the assessment results.

In June 2005, the region of Catalonia's AC presented the draft bill "Against Odourous Pollution" [60]. This draft was inspired by the first H4 Horizontal Guideline of the UK [48]. This draft received considerable pressure from the pig farming sector in Catalonia. This region is the main pork producer of Spain. Additionally, some political changes occurred in that region, having the consequence that the administrative procedure to approve the draft was finally interrupted. This draft was taken as a reference by many odour consultants in Spain.

In March 2019, the Canary Islands region sent to public inquiry the first regulation in Spain that sets odour limits. Again, political changes in the government prevented this regulation from being published.

In Spain, some small municipalities did regulate odours in the regions of Catalonia (Lliçà de Vall [61], Banyoles [62], Riudellots de la Selva [63], Sarrià de Ter [64], Valencia (Raspeig) [65], Murcia (Alcantarilla, San Pedro del Pinatar) [66,67], and the Canary Islands (Las Palmas) [68]. In the small town of Alcantarilla, the local odour regulation defines the areas with an "odour" saturation. This way, they limit the areas where an industrial facility that can potentially cause annoyance cannot be located or where the urban expansion has to be halted to avoid an odour impact. The OIC are set as 5 $ou_E \cdot m^{-3}$ (98th Percentile). The municipality of San Pedro del Pinatar set the OIC levels of the Catalonian draft.

The municipality of Las Palmas de Gran Canaria, similarly to San Vicente del Raspeig, has developed an "odour perception index" (IP) in its regulation. The equation to calculate the odour perception index is the following:

$$IP = \log 10\,(C) \times FC \times FD \times FI \times FP \times FV \quad (1)$$

where C is odour concentration, FC is the hedonic tone factor, FD is the emission factor's duration, FI is the intermittency factor of the processes, FP is the emission period factor (varies from 1.0 to 1.2 depending on the time of the day/week; the lower value is used for the working day hours (7:00–22:00, M–F), and the higher value is used for the night period (22:00–7:00)), and FV is the wind direction factor. The OIC, in this case, are set as an odour perception index of 0.04.

2.7. The Netherlands

The Netherlands has an overall odour regulation based on the Industrial Emission Directive (IED) for any activity in this regulation. There is specific odour legislation only for livestock farming. For all activities except livestock, the protection against odour nuisance is regulated in the Activities Decree [69]. The premise here is to prevent or reduce the odour to an acceptable level by applying BAT. Additionally, odour regulations may be included in a customised decision or a permit. The local government may decide what levels are acceptable or not, but there is no clear national-level odour evaluation framework to do so. The competent authority may set a local odour policy to help determine the acceptable odour nuisance level [70]. The majority of the Dutch provinces have done so, while cities usually do not have an odour policy of their own but make use of the provincial one.

The local odour policies are either based on percentile values already in use in the last century or on an odour's hedonic tone. Common standards in use over many years are the calculated 98th or 95th percentile values of 0.5, 1.5, and 5 $ou_E{\cdot}m^{-3}$, representing different levels of protection. Popular limit values in local policies are also those based on the hedonic tone of the odour. To do so, measurements of hedonic tone are carried out by an olfactometry laboratory, according to the Dutch standard for hedonic tone [71]. The hedonic tone is expressed on a scale from −4 (very unpleasant) to +4 (very pleasant). In general, it is assumed that an odour nuisance can occur at odour concentrations higher than the odour concentration corresponding to the hedonic value of −0.5 as the 98th percentile. At concentrations above the concentration corresponding to a hedonic value of H = −2, severe odour nuisance and odour complaints are likely to occur. While developing an odour framework, the odour concentration at which a certain scale value for hedonic tone is reached (for example, H = −2) is taken as a guide value for the 98th percentile. Differences in acceptable nuisance levels are made between existing and new situations and between the residential areas and "scattered" houses.

Examples of provinces with local odour evaluation frameworks are Flevoland, Gelderland, Groningen, North Brabant, Overijssel, South Holland, and Zeeland. The local evaluation frameworks vary from one province to another. While setting local evaluation criteria, provinces or municipalities can base themselves on the following documents and considerations:

The Dutch Emission Guidelines (NeR) aimed to harmonise the environmental permits' emission requirements in the Netherlands. It contained guidelines for air emissions from industrial processes, including odour evaluation criteria, varying from, for example, 0.5 $ou_E{\cdot}m^{-3}$ at the 98th percentile for sewage treatment plants to 5 $ou_E{\cdot}m^{-3}$ at the 98th percentile for bread bakeries [72]. At the beginning of 2016, the NeR was cancelled, but the normative part was included in the Activities Decree. As the odour evaluation criteria were not normative, they were not included in this decree. However, they are still used as guidelines when drawing up local odour evaluation frameworks.

The letter from the Ministry of Housing, Spatial Planning and the Environment states that in most cases, a serious odour nuisance can be avoided when emission concentrations are below 5 $ou_E{\cdot}m^{-3}$ as the 98th percentile (continuous emission sources). For sources with short emission durations, the 98th percentile concentrations do not reflect the expected odour nuisance. For these sources, the use of a higher percentile is more appropriate.

Generally, at 98th percentile odour concentrations with a hedonic tone less than H = −2, a serious odour nuisance will occur (continuous emission sources). At odour concentrations below 0.5 $ou_E \cdot m^{-3}$ as the 98th percentile (and a hedonic tone not less than H = −0.5), no nuisance is expected (continuous emission sources).

The Law of 5 October 2006 on Livestock Odour Control of the Ministry of Housing, Spatial Planning and the Environment [73] of the Netherlands regulates odour nuisances caused by animal accommodation used in livestock farming. It contains some OIC for dwellings in the surrounding livestock farms. Limit values differ between 2 $ou_E \cdot m^{-3}$ as the 98th percentile for residential areas up to 8 or 14 $ou_E \cdot m^{-3}$ as the 98th percentile for rural areas. Those limit values were based on dose–response relationships which followed large investigations on odour emissions and odour nuisance around livestock farms in 2001 [74].

This legislation [75] contains the determination of odour emission factors, minimum distances for fur-bearing animals, the method of calculating odour intensity, and the method of determining the distance. This regulation is reviewed every year to add necessary changes.

The regulation appears to be based on the rationale that not all livestock operations are equal; i.e., it gives some odour emission factors depending on the animal type. Further, it regulates the separation distance stating that the setback distance between a livestock farm and an odour-sensitive receptor must be at least 100 (if the odour-sensitive receptor is situated in the built-up area) or 50 m (outside the built-up area). If animals are also kept in an animal category with no determined odour emission factor, a minimum distance of 50 to 100 metres must also be observed from the facilities where the animals are kept.

The present Law on Livestock Odour Control [73] is being reviewed at the moment. Health research over recent years [76] has shown unexpected high levels of nuisance (and lung diseases) in dense livestock areas. The possible revision of its content tends to lower acceptable intensity levels and enlarging setback distances. New investigations on health effects around livestock farms, including odour nuisance, as well as on possible measures, (BAT) are carried out to fundamentally review the law on this subject. An example of such investigation is the research reporting a strong relation between modelled odour exposure from livestock farming and odour annoyance among neighbours [77]. Public health authorities nowadays advise to use limit values of 2 $ou_E \cdot m^{-3}$ as the 98th percentile for residential areas, and no more than 5 $ou_E \cdot m^{-3}$ as the 98th percentile for rural areas [78].

2.8. Italy

Italy does not have a national-level regulation regarding odour. However, some efforts have been made at a regional level. The first regional regulation mentioning odour was the 2003 guideline of the region of Lombardy which covered the construction and operation of compost production facilities [79]. This guideline fixed some limit values for atmospheric emissions, thereby including a limit of 300 $ou_E \cdot m^{-3}$ relevant to odour emissions. Despite the old approach of giving an odour concentration value and the fact that this guideline is now obsolete (no longer valid), it is worth mentioning due to its historical significance.

Almost ten years later, in 2012, the region of Lombardy again acted as a pioneer in Italy by publishing a regional guideline specifically on odour emissions ("General determinations regarding the characterization of atmospheric emissions from activities with a high odour impact" [80]). This regional guideline was inspired by other regulations in Europe and adopted a more modern approach, based on odour dispersion modelling. The guideline does not have explicit acceptability criteria. However, it specifies that any plant with an odour impact shall evaluate the extent of this impact by drawing up impact maps indicating annual peak odour concentration values at the 98th percentile, thereby drawing the 98th percentile iso-concentration lines corresponding to the odour concentration values: 1, 3, and 5 $ou_E \cdot m^{-3}$, as resulting from atmospheric emission dispersion simulations (see example in Figure 2).

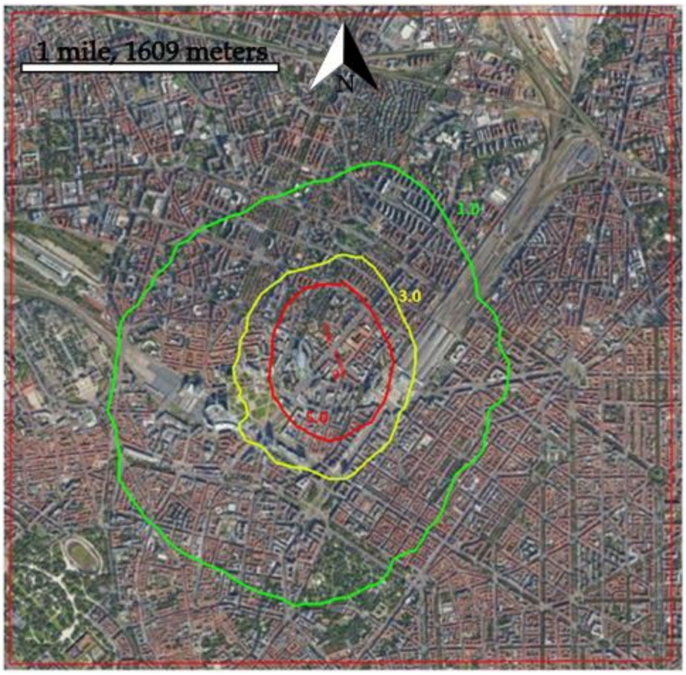

Figure 2. Example of a map resulting from atmospheric dispersion simulations representing the iso-concentration lines corresponding to the 98th percentile of the odour concentration values of 1, 3, and 5 $ou_E \cdot m^{-3}$.

Even though this approach is not particularly original concerning other European regulations, the guidelines present some innovative aspects that are worth highlighting. Annexe 1 fixes the requirements of the odour impact studies by emission dispersion simulation. Besides establishing criteria for input data quality and presentation of results, some other indications are provided regarding the dispersion model to be used. An interesting observation is that Gaussian models are excluded from the suggested models. This is further highlighted by the specification of the necessity for the model to treat calm winds, which are typical of the Lombard territory.

Another interesting aspect of this guideline is the precise definition given in Annexe 2 of the sampling procedures for gathering odour emission data from different source types, i.e., measuring representative odour concentrations and then evaluating odour emission rates which are required as model inputs. This aspect is particularly innovative, especially compared to EN 13725:2003 [1], which is extremely lacking in details of sampling procedures.

One positive aspect of this guideline is that it is based on a rather simple and sequential approach, and the required economic investment for its application is quite contained. The approach has been successfully accepted both by local authorities and plant owners or managers. Besides having raised the awareness of authorities and the public towards environmental odour pollution management, in some situations, the adoption of the Lombard guideline has already led to the identification and solution of odour problems for existing plants, or to the proper modification of the projects of new plants in order to limit their predicted odour impact to an acceptable extent.

Even though the guideline mentioned above is a regional guideline, it is currently used as the regulatory reference for most other Italian regions. Indeed, the region of Piemonte and the autonomous province of Trento have very recently issued their odour guidelines, which are substantially a copy of the Lombard guideline [81]. The latter's main innovation is that it fixes acceptability criteria in terms of the 98th percentile peak odour concentration limits that vary in function of the receptor distance from the source (Table 6).

Table 6. Proposed odour impact criteria (OIC) for the Italian province of Trento (98th percentile) [81].

Receptors in Residential Areas	
OIC (98th Percentile)	**Distance from the Source**
1 $ou_E \cdot m^{-3}$	>500 m
2 $ou_E \cdot m^{-3}$	200–500 m
3 $ou_E \cdot m^{-3}$	<200 m
2 $ou_E \cdot m^{-3}$	>500 m
3 $ou_E \cdot m^{-3}$	200–500 m
4 $ou_E \cdot m^{-3}$	<200 m

A different approach was proposed in the region of Puglia, with the publication of the D.g.r. 16 April 2015 [82]. This regional regulation is mainly based on an analytical approach to measure the "limit concentration" of 40 different odourous chemical compounds, each according to a specific analytical technique. The guideline also fixed odour concentration limits in terms of 2 000 $ou_E \cdot m^{-3}$ for point sources and 300 $ou_E \cdot m^{-3}$ for diffuse sources. This regional regulation has been strongly criticised because of its excessively complex approach—implying high costs of debatable usefulness for extensive chemical analyses—and to the fact that its principles are unnecessarily different from those adopted elsewhere since chemical analyses have been abandoned almost everywhere as a reference method for odour emission measurement.

2.9. Belgium

Belgium has federal and regional legislation. For environmental matters, the federal government and the regions share responsibility for the implementation of environmental policies. The competence in the evaluation of the odour impact lies in the Flemish and Wallonia region. The two regions have their own specificities.

Odour control is mainly based on the field inspection—the plume method, according to EN 16841-2 [4]. Following the plume method, the global emission rate is determined using the odour concentration at the receptor level and a reverse modelling approach. Odour dispersion modelling is frequently performed with the ADMS model in Wallonia and with the IMPACT model in Flanders (for both: 1 h mean values, peak-to-mean factor of 1).

The emission rate entered into the dispersion model is adjusted until the simulated average isopleths for 1 $su \cdot m^{-3}$ (su: "sniffing" unit) at about 1.5 m height fit the observed perimeter and the maximum perception distance. For field measurement, the results have to be expressed in "su" and not in ou. The reason is to make a clear distinction between the concentration of odour, collected in bags, measured according to EN 13725 [1], and the concentration obtained by field inspection. A fundamental difference with the European odour unit is that sniffing units are based on recognition of odour, whereas European odour units are determined by detection and not necessarily a recognition of the odour type. One sniffing unit per cubic metre is defined as the odour concentration at the border of the plume. It is impossible to quantify higher concentrations (e.g., 5 $su \cdot m^{-3}$) by observation in the field. Typically, 1 $su \cdot m^{-3}$ corresponds to a concentration of 1 to 5 $ou_E \cdot m^{-3}$.

Typically, about ten campaigns have to be organised over at least five different days in order to take most variations into account. Finally, the mean emission rate is calculated and introduced into the same dispersion model for the region's normal reference year to calculate the percentiles.

2.9.1. Walloon Region

There is no general legislation concerning odours in the Walloon region. The approach has been to provide guidelines for different activities. For example, there are specific regulations dealing with odour management for composting plants and farms. In the case of composting plants, the Walloon Decree from 2009 (2009/204053) [83] states that the odour concentration must not be greater than 3 $ou_E \cdot m^{-3}$ at the 98th percentile to the closest neighbour. In the case of farms, it is based on the calculation of a minimum separation distance to prevent odour annoyance [84]. The requirements for farms depend on the sector's area plan where they are established and whether the farm is new or existing. These values are not yet fully validated and are not yet compiled in a Walloon decree. Table 7 below shows the different guidelines.

Table 7. Odour impact criteria for the farming sector in Wallonia [83].

Area of the Sector Plan	OIC (98th Percentile)	
	Existing Farm	New Farm
Habitat area	3 $ou_E \cdot m^{-3}$	1 $ou_E \cdot m^{-3}$
Recreation area	3 $ou_E \cdot m^{-3}$	1 $ou_E \cdot m^{-3}$
Public service area	3 $ou_E \cdot m^{-3}$	1 $ou_E \cdot m^{-3}$
Cultivated area	10 $ou_E \cdot m^{-3}$	6 $ou_E \cdot m^{-3}$
Other areas	6 $ou_E \cdot m^{-3}$	3 $ou_E \cdot m^{-3}$

The AWAC (Walloon Agency for Air and Climate) is still working towards updating the Walloon odour regulation.

Besides the composting decree and the farming guidelines, the general rule is to define the conditions in the operating permits delivered by the Department of Permits and Authorizations (DPA) or the communes. Each of the four existing DPA (Namur-Luxembourg, Liège, Charleroi, Mons) works differently. Each activity is case-specific and whether an environmental permit is granted depends on the type of odours and their impact on the neighbourhood. By default, an odour concentration of 1 $ou_E \cdot m^{-3}$ at the 98th percentile is imposed.

The method used to measure odours is not set by any regulation. However, the lab/agency that carries out the odour concentration measurement by dynamic olfactometry [1] requires the Wallonia agreement. The way to check the OIC values set in a permit/authorisation depends on the environmental consultancy agency or the lab that performs the control. The organism in charge of checking the OIC has to justify to the DPA why they used that methodology. For example, the field inspection method is usually performed in municipal solid waste landfills [85–87]). The Walloon Environmental Police Division (DPE) has competence in both environmental permitting and complaint management. A new trend is to promote the use of resident diaries ("watchmen"). This approach is considered relevant by the DPE and efficient in solving odour annoyance [88].

2.9.2. Flemish Region

As far as odour nuisance is concerned, there is no legal framework in the Flemish region either. The Flemish odour policy is based on the following basic rules [89]: (1) when there is a nuisance, BAT measures must be taken to reduce it, (2) when there is no nuisance, no measures must be taken, (3) a severe odour nuisance is never acceptable, and (4) zero-emissions are not realistic.

While performing odour assessment studies, one of the key concepts is the "acceptable nuisance level". This level is situated between the no-effect level or target value and the limit value. The no-effect level is defined as the nuisance level from which no further decline in annoyance is observed; the limit value is the nuisance level at which severe nuisance occurs (structural complaints). Both values are expressed as 98th percentile concentration values. The acceptability level is determined, taking into account some environmental, legal, social, economic, financial, technological, and contextual aspects.

The way the target level, the limit level, and the acceptable nuisance level are derived is case-specific and must be determined by the odour consultant or odour lab that performs the odour assessment study. Some of the guidelines for doing this are summarised below [89].

For slaughterhouses and wastewater treatment plants (WWTPs), no effect levels or and limit values were scientifically determined based on dose–response studies derived from elaborate studies at different companies ([90,91] see Table 8). For some other odour-emitting sectors, only the no-effect levels were determined (see Figure 3). Some of these levels are determined based on dose–response relationships; others are deduced based on the hedonic tone of the odour.

Table 8. Target values and limit values for slaughterhouses and wastewater treatment plants (WWTPs) [92].

Sources	Target Value (No-Effect Value) [su·m^{-3} as 98th Percentile]	Limit Value [su·m^{-3} as 98th Percentile]
Slaughterhouses	0.5	1.5
WWTPs	0.5	2.0

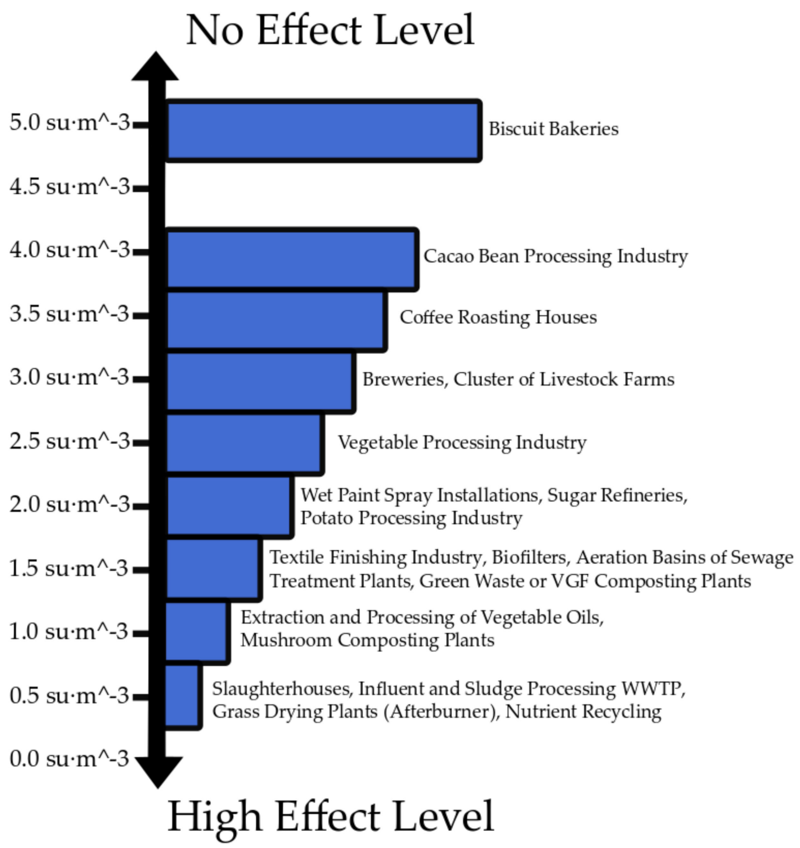

Figure 3. No-effect levels for different sectors [93].

Table 9 shows the no-effect levels for odours/sectors not mentioned in Figure 3:

Table 9. Target values not mentioned in Figure 3 [93].

Hedonic Tone	Target Value [su·m^{-3} as 98th Percentile]
strongly unpleasant	0.5
unpleasant	1.0–1.5
neutral	2.0
pleasant	2.5–3.0
strongly pleasant	3.5–5.0

The above-mentioned target values and limit values are used for odour impact assessment in highly sensitive places/areas (e.g., residential areas). If the limit value is exceeded, the odour impact is considered to be significantly negative. If the target value is exceeded, the odour impact is considered to be negative.

For moderate to low sensitive areas (e.g., industrial areas), the odour evaluation framework is less severe, and higher target and limit values are used. Table 10 shows the target and limit values for strongly unpleasant odours as a function of the odour sensitivity of the area. The odour evaluation framework based on these criteria is given in Table 11.

Table 10. Target and limit values as a function of the odour sensitivity of the area (strongly unpleasant odours) [93].

Odour Sensitivity of the Area	Target Value [su·m^{-3} as 98th Percentile]	Limit Value [su·m^{-3} as 98th Percentile]
Highly odour-sensitive locations	0.5	2.0
Moderate odour-sensitive locations	2.0	5.0
Low odour-sensitive locations	3.0	10

Table 11. Odour impact evaluation framework for strongly unpleasant odours [93].

98th Percentile-Concentration. [su·m^{-3}]	Low Odour-Sensitive Places	Moderate Odour-Sensitive Places	Highly Odour-Sensitive Places
>10	Significantly negative impact	Significantly negative impact	Significantly negative impact
5–10	N negative impact	Significantly negative impact	Significantly negative impact
3–5	Negative impact	Negative impact	Significantly negative impact
2–3	Negligible impact	Negative impact	Significantly negative impact
0.5–2	Negligible impact	Negligible impact	Negative impact
<0.5	Negligible impact	Negligible impact	Negligible impact

Similar odour evaluation frameworks can be derived for other types of odours.

In 2015 and 2018, sectoral Codes of Good Practice for prevention, assessment, and control of odour nuisance caused by asphalt plants and WWTPs were developed, including an odour evaluation framework [94,95]. For asphalt plants, the target and limit values (for highly sensitive areas) are fixed at 1 and 2.5 su·m^{-3} as the 98th percentile. As asphalt plants are non-continuous odour sources, also 99.99 percentile target and limit values are used. For asphalt plants producing 15 to 25% of the time, the target and limit values are fixed at 5 and 12.5 su·m^{-3} as the 99.99 percentile.

For WWTPs, a distinction is made between the sources that cause a very unpleasant odour (e.g., the primary treatment, sludge storage, and treatment) and sources that cause a neutral odour (such as the biological treatment). The impact of both odour types is determined in separate dispersion calculations. For the very unpleasant odours, the target and limit values given in Tables 10 and 11 are used. The target and limit values (for highly sensitive areas) are fixed at 1 and 2.5 su·m^{-3} as the 98th percentile. For the neutral odours, these values are, respectively, 1.5 and 3 su·m^{-3} as the 98th percentile. For less sensitive areas, higher target and limit values are used.

One last sector for which an odour impact evaluation framework was derived is livestock farming. In the environmental impact assessment guidebook for livestock farming [95], the following odour evaluation framework is included, which distinguishes between isolated livestock farms and livestock farms that belong to a cluster (Tables 12 and 13). The values in this framework are expressed in ou_E·m^{-3} (i.e., not in sniffing units). (Note: a livestock farm belongs to a cluster when one or more other farms are situated in the no-effect level contour (0.5 ou_E·m^{-3} as the 98th percentile) of the farm under investigation. Only livestock farms with odour emissions higher than 5% of the farm's odour emission under investigation should be taken into account).

Table 12. Odour impact evaluation framework for isolated livestock farms [96].

Concentration as 98% [$ou_E \cdot m^{-3}$]	Scattered Houses in Agricultural Area	Residential Area with Rural Character	Residential Area
>10	Significantly negative impact	Significantly negative impact	Significantly negative impact
3–10	Negative impact	Significantly negative impact	Significantly negative impact
1.5–3	Small negative impact	Negative impact	Significantly negative impact
1–1.5	Negligible impact	Small negative impact	Negative impact
0.5–1	Negligible impact	Negligible impact	Small negative impact
<0.5	Negligible impact	Negligible impact	Negligible impact

Table 13. Odour impact evaluation framework for livestock farms belonging to a cluster [96].

Concentration as 98th Percentile [$ou_E \cdot m^{-3}$]	Scattered Houses in Agricultural Area	Residential Area with Rural Character	Residential Area
>10	Significantly negative impact	Significantly negative impact	Significantly negative impact
5–10	Negative impact	Significantly negative impact	Significantly negative impact
3–5	Small negative impact	Negative impact	Significantly negative impact
<3	Negligible impact	Negligible impact	Negligible impact

3. Australia and New Zealand

Odours are the largest source of air pollution complaints in Australia (AU) and New Zealand (NZ). In AU and NZ, odour is managed and legislated in much the same way as other noxious pollutants such as SO_2 and NOx. Odour is controlled under the Protection of the Environment Operations Act 1997 in AU and the 1991 Resources Management Act of New Zealand, and the Resource Management Regulations of 2004 [97]. Strict odour assessment criteria exist in both countries.

Odour assessment criteria in AU and NZ are primarily used to compare odour concentrations from dispersion model outputs, in $ou \cdot m^{-3}$, to the respective country and state odour guideline values to determine whether objectionable or offensive effects are likely to occur, although there appears to be an increase towards a risk-based assessment approach, i.e., Western Australia. In general, the odour assessments in both countries take into account the following:

Odour guideline documents accompany each state in AU, with a single guideline document in NZ. It is emphasised that the guidelines and odour assessment criteria therein are not meant to be interpreted as a "pass or fail" test. The guidelines aim to provide a framework for effective project planning and a regulatory regime for odour-emitting activities. Other key points relating to odour assessment as per the AU and NZ guidelines are as follows.

Odour unit has the same meaning as that in the Australia and New Zealand Standard AS/NZS 4323.3, Stationary source emissions—Determination of odour concentration by dynamic olfactometry.

Peak-to-mean ratio. In New South Wales and Queensland, a "user-applied" conversion factor adjusts the mean dispersion model predictions to the peak concentrations perceived by the human nose. In New South Wales, the peak-to-mean value varies depending on whether the source is wake-free or wake-affected (due to structures), the source characteristics, the distance from the source, and atmospheric stability. In Queensland, the peak-to-mean value depends solely on whether a source is wake-free or not. In NZ and some states of AU, the peak-to-mean value has already been included in the odour assessment criteria. The peak-to-mean values can be applied to the emission rates or to the predicted odour concentrations.

Various percentile limits of 100%, 99.9%, and 99.5% are used throughout both countries. The percentiles allow for a small level of exceedances of the concentration predictions to account for the worst-case meteorological conditions, at which objectionable odours are unlikely to occur because the conditions occur infrequently or not at all.

Table 14 below presents the odour assessment criteria used throughout Australia and New Zealand, and Table 15 presents the peak-to-mean ratios applied in New South Wales, Australia, while Table 16 presents the peak-to-mean ratios applied in Queensland, Australia.

Table 14. Odour assessment criteria for New South Wales [98], Western Australia [99], Australian Capital Territory (ACT) [100], South Australia [101], Queensland [102], Victoria [103], and Tasmania [97] in Australia as well as New Zealand [104].

Odour Assessment Criteria	New South Wales Australia	Western Australia	ACTEW and South Australia	Queensland Australia	Victoria Australia	Tasmania Australia	New Zealand
Impact assessment criteria	2.0–7.0 ou Log scale based on population density	WA prefers a risk-based approach	2.0–7.0 ou ACT 2.0–10.0 SA Log scale based on population density	5 ou	Varies 5.0 ou Broiler farms 1.0 New Developments	2.0	1.0–10.0 ou Depends on the sensitivity of the receiving environment
Percentile value	99th or 100th Depends on the quality of Met and Emission Data	Dispersion modelling is no longer the first response	99.9	99.5	99.9	99.5 or 99.9 For an unknown and known mixture, respectively. Or, 100 if good-quality Met and Emissions	99.5 and 99.9
Averaging period	1 h but criteria are equivalent to 1 s	1 h	3 min	1 h	3 min	1 h	1 h
Peak-to-mean ratio	Peak-to-mean ratio applied by user to 1-h averaged conc. See Table 15.	Modelling is not used to compare against ou criteria	No peak-to-mean value applied but conc. must be scaled to 3 min using power law equation	Peak-to-mean ratio of 10:1 and 2:1 for wake-free and wake-affected + ground sources	No peak-to-mean applied but conc. must be scaled to 3 min using the power law equation	Peak-to-mean ratio is included in odour assessment criteria	Peak-to-mean ratio is included in odour assessment criteria

Table 15. Peak-to-mean values used in New South Wales, Australia [98].

Source Type	Stability Class (Unstable and Neutral) A, B, C, D	Stability Class (Stable) E, F
Area	2.5	2.3
Wake-affected point	2.3	2.3
Wake-free point	12	25
Volume	2.3	2.3

Table 16. Peak-to-mean values used in Queensland, Australia [102].

Source Type	Peak-to-Mean Value
Wake-affected point and all ground-based sources	2.0
Wake-free point	10.0

New South Wales further defines the peak-to-mean values as "near"-field or "far"-field. Near- and far-field distances are defined as "less than" and "greater than" ten times the largest source dimension.

For an unstable and neutral atmosphere, "near-field" area sources use a peak-to-mean value of 2.5, and for "far-field", a peak-to-mean value of 2.3. For a stable atmosphere, "near-field" area sources use a peak-to-mean ratio of 2.3, and for "far-field", a peak-to-mean value of 1.9.

In Queensland, "user-applied" peak-to-mean values are 2.0 for all wake-affected point sources and all ground-based sources. The peak-to-mean value is 10.0 for all wake-free point sources.

All peak-to-mean values in AU and NZ are based in some way on the original Katestone Scientific work [105,106] conducted in 1995 on behalf of the Environment Protection Authority of New South Wales.

Neither AU nor NZ provides different odour assessment criteria according to odour activity. This means that a broiler farm is assessed at the same odour rate as a piggery or a layer hen farm. However, odour assessment criteria can range depending on the size of the nearby potentially affected population. In several states in AU, namely, New South Wales, South Australia, and ACT (Canberra), a range of odour assessment criteria is applicable depending on the sensitivity of the population as determined by population numbers. For example, in New South Wales, a single residence is assessed at 7 ou, whilst for larger populations, where there will be a greater range of sensitivities to odour and a higher number of more sensitive individuals, the acceptable odour limit is defined as 2 ou. If an odour source is in an area with a rural residence to the north and a town of 500 people to the south, then the appropriate criterion would be 7 ou for the single residence and 3 ou for the town and adjoining houses.

In New Zealand, under the Resource Management Act, the environment's sensitivity must be taken into account and should be considered as part of any odour assessment. This is dictated by the district plan's provisions, which set out amenity expectations for each land use type. The sensitivity in a particular location is based on the characteristics of the land use, including the time of day and the reason people are at a particular location. For example, "people driving past a broiler farm may not find the odours offensive as their exposure is very brief. Similarly, odours from natural sources, such as mudflats or geothermal activity, are unlikely to be deemed offensive. However, people attending a wedding at a church may find odours from an anaerobic oxidation pond at a neighbouring wastewater treatment plant to be extremely offensive" [107].

In New Zealand, the sensitivity of the receiving environment is assessed according to three land use categories; highly sensitive, medium sensitivity, and low sensitivity. Hospitals, schools, childcare facilities, and residential areas are all assessed as highly sensitive, whilst a rural area that can carry just a handful of residences can be rated as having both high sensitivity and low sensitivity. The thinking goes that people "living in and visiting rural areas generally have a high tolerance for rural activities but they are still sensitive to other types of activities (e.g., industrial activities)" [107]. Along with this ambiguity of high and low sensitive land use activities, two different odour assessment criteria exist, where a highly sensitive area carries an odour assessment criteria of 2 ou and a low sensitive area is assessed at 10 ou.

Table 17 below provides the range of odour assessment criteria per population numbers for those states that include it. Table 18 includes the New Zealand odour assessment criteria as per sensitive land use types.

Western Australia has recently published its new June 2019 guideline document [99]. This new guideline does not recommend the comparison of the dispersion model output with the odour assessment criteria. The WA guideline has provided a range of emission sources, pathways, and receptor tools for analysing an odour that does not involve modelling. Emphasis is put on the characterisation of odour sources, field assessments, and analysis of the complaints register. Dispersion modelling is only recommended for "comparative" assessments. This refers to the comparison of two or more modelling scenarios without specific reference to air emission criteria.

Table 17. Odour assessment criteria range according to population numbers in South Australia, New South Wales, and ACT, and New Zealand [98,100,104].

South Australia (3-min Average 99.9 Percentile)		New South Wales (1-s *1 Average 99.9 Percentile)	
Number of People	**ou**	**Number of People**	**ou**
2000 or more	2	2000 or more	2
350 or more	4	Approx. 500	3
60 or more	6	Approx. 125	4
		Approx. 30	5
12 or more	8	Approx. 10	6
Single Residence	10	Single Residence	7
High Density	2	1 person or 2000 persons	1–10
300 or more	3		
50 or more	5		
10 or more	6		
Less than 10	7		

*1 Nose response time = 1 s averaging time.

Table 18. Details of the NZ sensitivities of the receiving environment [107].

Sensitivity of the Receiving Environment	Concentration	Percentile
High *1 (worst-case impacts during unstable to semi-unstable conditions)	1 ou·m^{-3}	0.1 and 0.5
High *1 (worst-case impacts during neutral to stable conditions)	2 ou·m^{-3}	0.1 and 0.5
Moderate *2 (all conditions)	5 ou·m^{-3}	0.1 and 0.5
Low *3 (all conditions)	5–10 ou·m^{-3}	0.5

*1 High sensitivity includes rural, rural residential, countryside living, commercial, and retail business. *2 Moderate sensitivity includes commercial, retail business, rural residential, countryside living, and light industry. *3 Low sensitivity includes rural, heavy industry, and public roads.

4. China

4.1. Background and Overview

The Chinese emission standard for odour pollutants [108] can be found at website of Ministry of Ecology and Environment of the People's Republic of China. The standard is only available in the Chinese language, with the title and keywords explained in English.

While odour legislation in Europe, America, and Australia is focused on minimising odour concentrations at receptors, with usually no specific requirements on odour emissions from the sources, the odour legislations in East Asian countries such as China and Japan have regulations both on disorganised odour emissions and on discharge limits from stacks. This is likely due to the higher population density in these areas, where odour pollution can be dense and complicated for tracking sources.

4.2. Odour Impact Assessment in the People's Republic of China (PRC)

In China, the emission standard for odour pollutants GB 14554-93 [108] is still valid even though it was legislated in 1994. An example of the validity of this standard is shown on the PRC environment website in a case dealing with odour pollutants (hydrogen sulfide and carbon disulfide) emitted from industry in 2007. Nevertheless, a revision of the standard GB 14554-93 is in progress, with the call for comments closed in March 2010. The consultation paper was released in December 2018, and the new version of this standard is therefore expected to be released soon (with more strict emission standards expected). GB 14554-93 [108] stated boundary odour concentrations and standard concentrations for disorganised odour emissions of eight odourants, as shown in Table 19. Industries such as livestock and poultry breeding have a specific pollutant discharge standard with an odour concentration limit of 70 [109]. Meanwhile, the GB 14554 standard [108] also legislated the discharge limit for the emissions of eight odourants and odour concentrations from stacks, as shown in Tables 20 and 21. Depending on stack height, various levels of emission rates standards ($kg \cdot h^{-1}$) were given, with higher emission rates allowed under higher stack height. The odour concentration detection follows the "triangle odour bag method" [110], which is now also under revision. The "triangle odour bag method" requires six sniffing members each for sniffing three bags in which two bags are references with clean air inside. If the sniffing member can recognise the bag with an odour sample, the odour sample bag will then be diluted for the next level of sniffing until no recognition can be made among the three bags. The odour concentration can thus be estimated based on dilutions.

Table 19. Boundary standard values of odour pollutants ($mg \cdot m^{-3}$) [111]. Names are formatted to the "IUPAC (common name)" convention.

Pollutant	Class 1 [*1]	Class 2 BER [a] [*2]	Existing	Class 3 BER [a] [*3]	Existing
Azane (ammonia)	1.0	1.5	2.0	4.0	5.0
N,*N*-dimethylmethanamine (trimethylamine)	0.05	0.08	0.15	0.45	0.8
Sulfane (hydrogen sulfide)	0.03	0.06	0.10	0.32	0.6
Methanethiol (methyl mercaptan)	0.004	0.007	0.010	0.020	0.035
Methylsulfanylmethane (dimethyl sulfide)	0.03	0.07	0.15	0.55	1.1
(Methyldisulfanyl)methane (dimethyl disulfide)	0.03	0.06	0.13	0.42	0.71
Carbon disulfide	2.0	3.0	5.0	8.0	19
Styrene (vinyl benzene)	3.0	5.0	7.0	14.0	19
Odour concentration [b]	10	20	30	60	70

[*1] Class 1—natural conservation areas, scenic areas, historical sites, and regions requiring special protection; [*2] Class 2—residential areas, areas of mixed activity (e.g., commercial and traffic, residential, cultural, industrial, and rural); [*3] Class 3—special industrial areas; [a] newly built, extended, or rebuilt (BER); [b] dimensionless.

The emission standards for odour pollutants of GB 14554-93 [108] have some drawbacks, partly because this is the first standard on odour in China, and it is now ~27 years old. First, the odour pollutants did not cover a wide representation from all industries with only the eight odourants.

Second, the three classes (Class 1, 2, and 3) based on which the standard boundary values were set were adopted from the Chinese Ambient Air Quality Standard GB3095-1996 [112]. However, this standard has been revised, and the new version considers only two classes of industrial area and non-industrial area for air quality. This standard was implemented in January 2016 [113], and thus should be revised accordingly.

Third, the different limits on the discharge of odourants as a function of the stack height are obstacles for applications of advanced odour reduction technologies since the industry has tried to avoid these new technologies by making a higher stack (and thus allowing a higher emission discharge) [114].

The local emission standards for odour pollutants [112] for the Shanghai area were implemented from 1 February 2017. In this standard, discharge limits were set for odour concentrations under various stack height levels for two classes of odour sources: industrial and other sources (Table 22).

Table 20. The discharge limits of emission rates for the 8 odourants and for the odour concentrations from stacks, where the IUPAC common name is provided in pararenthesis. O1—hydrogen sulfide (sulfane); O2—methyl mercaptan (methanethiol); O3—methylsulfanylmethane (dimethyl sulfide); O4—dimethyl disulfide ((methyldisulfanyl)methane); O5—carbon disulfide; O6—ammonia (azane); O7—trimethylamine (*N*,*N*-dimethylmethanamine); O8—vinyl benzene (styrene) [114].

Stack Height (m)	Discharge Limit of Emission Rate (kg·h^{-1})							
	O1	O2	O3	O4	O5	O6	O7	O8
15	0.33	0.04	0.33	0.43	1.5	4.9	0.54	6.5
20	0.58	0.08	0.58	0.77	2.7	8.7	0.97	12
25	0.90	0.12	0.90	1.2	4.2	14	1.5	18
30	1.3	0.17	1.3	1.7	6.1	20	2.2	26
35	1.8	0.24	1.8	2.4	8.3	27	3.0	35
40	2.3	0.31	2.3	3.1	11	35	3.9	46
60	5.2	0.69	5.2	7.0	24	75	8.7	104
80	9.3				43		15	
100	14				68		24	
120	21				97		35	

Table 21. The discharge limits of odour concentrations from stacks [114].

Stack Height (m)	Standard for Odour Concentration (Dilutions)
10	2000
20	6000
30	15,000
40	20,000
50	40,000
≥60	60,000

Table 22. The discharge limit for odour concentrations from stacks in the Shanghai area [115].

Pollutant	Stack Height (H; m)	Industrial Source	Non-Industrial Source
Odour Concentration	H < 15	500	800
	15 ≤ H < 30	1000	1000
	30 ≤ H < 50	1500	1500
	H ≥ 50	3000	3000
Odour Pollutants	H ≥ 15	See Table 21	

Compared to the national emission standard GB 14554-93 [108], this emission standard of odour concentration in Shanghai is much more stringent, with 500 (for the industrial area) or 800 (for the non-industrial area) compared to 2 000 under a stack height of 15 m or less. Further, 22 odourants were set for discharge limitations under a stack height of 15 m, both for the emitted concentration (mg·m^{-3}) and for the emission rate (kg·h^{-1}) (Table 23).

The standard on emitted concentrations was not included in the national standard of GB 14554-93 [108], while 14 more odour pollutants are newly included in the Shanghai standard. In addition, no difference was set for the Shanghai emission standard of odour pollutants under various stack heights, with apparently more stringent emission rate standards on single odour pollutants (e.g., for H_2S, 0.1 kg·h^{-1} in the Shanghai standard while ≥0.33 kg·h^{-1} in the national standard GB 14554-93). For fugitive odour emissions not emitted from specific stacks, limits of 20 and 10 dilutions were set for industrial areas and not-industrial areas, respectively. Additionally, further limits were set for 22 odourants for both typologies of land use (Table 24).

Table 23. Discharge limits for odour pollutants in the Shanghai area [115]. Names are formatted to the "IUPAC (common name)" convention.

Number	Pollutant	Maximum Acceptable Emission Concentration ($mg{\cdot}m^{-3}$)	Maximum Acceptable Emission Rate * ($kg{\cdot}h^{-1}$)
1	Azane (Ammonia)	30	1
2	Sulfane (Hydrogen sulfide)	5	0.1
3	Methanethiol (Methyl mercaptan)	0.5	0.01
4	Methylsulfanylmethane (Dimethyl sulfide)	5	0.1
5	(Methyldisulfanyl)methane (Dimethyl disulfide)	5	0.26
6	Carbon disulfide	5	1
7	Styrene (Vinyl benzene)	15	1
8	Ethylbenzene	40	1.5
9	Propanal (Propionic aldehyde) #	20	0.3
10	Butanal (Butyraldehyde) #	20	0.2
11	Pentanal (Valeraldehyde) #	20	0.2
12	Butan-2-one (Methyl ethyl ketone) #	50	5
13	4-methylpentan-2-one (Methyl isobutyl ketone) #	80	3
14	Prop-2-enoic acid (Acrylic acid) #	20	0.5
15	Methyl prop-2-enoate (Methyl acrylate) #	20	1
16	ethyl prop-2-enoate (Ethyl acrylate) #	20	1
17	Methyl 2-methylprop-2-enoate (Methyl methacrylate) #	20	0.6
18	Methanamine (Methylamine) #	5	0.11
19	*N*-methylmethanamine (Dimethylamine) #	5	0.15
20	*N*,*N*-dimethylmethanamine (Trimethylamine)	5	0.2
21	Ethyl acetate	50	1
22	Butyl acetate	50	1

*—if the efficiency of odour abatement technologies is higher than 95%, this criterion is by default fulfilled.
#—only implemented after the national standards of analytical methods were released.

Table 24. Boundary standard values for disorganised odour emissions in the Shanghai area [115]. Names are formatted to the "IUPAC (common name)" convention.

Number	Pollutant	Industry Area ($mg{\cdot}m^{-3}$)	Non-Industry Area ($mg{\cdot}m^{-3}$)
1	Azane (Ammonia)	1.0	0.2
2	Sulfane (Hydrogen sulfide)	0.06	0.03
3	Methanethiol (Methyl mercaptan)	0.004	0.002
4	Methylsulfanylmethane (Dimethyl sulfide)	0.06	0.02
5	(Methyldisulfanyl)methane (Dimethyl disulfide)	0.06	0.04
6	Carbon disulfide	2.0	0.3
7	Styrene (Vinyl benzene)	1.9	0.7

Table 24. *Cont.*

Number	Pollutant	Industry Area ($mg \cdot m^{-3}$)	Non-Industry Area ($mg \cdot m^{-3}$)
8	Ethylbenzene	0.6	0.4
9	Propanal (Propionic aldehyde)	0.26	0.08
10	Butanal (Butyraldehyde)	0.14	0.06
11	Pentanal (Valeraldehyde)	0.11	0.04
12	Butan-2-one (Methyl ethyl ketone)	2.0	1.0
13	4-methylpentan-2-one (Methyl isobutyl ketone)	1.2	0.7
14	Prop-2-enoic acid (Acrylic acid) #	0.6	0.11
15	Methyl prop-2-enoate (Methyl acrylate) #	0.7	0.4
16	ethyl prop-2-enoate (Ethyl acrylate) #	0.4	0.4
17	Methyl 2-methylprop-2-enoate (Methyl methacrylate) #	0.4	0.2
18	Methanamine (Methylamine) #	0.05	0.03
19	*N*-methylmethanamine (Dimethylamine) #	0.06	0.04
20	*N*,*N*-dimethylmethanamine (Trimethylamine)	0.07	0.05
21	Ethyl acetate	1.0	1.0
22	Butyl acetate #	0.9	0.4
23	Odour concentration	20 *	10 *

*—dimensionless; #—only implemented after the national standards of analytical methods were released.

The standard boundary limit values for the Shanghai standard generally show lower values than the national standard GB 14554-93 [108] for industrial and non-industrial areas. On the other hand, this standard includes 14 more odourants.

In addition, the "Technical specification on environmental monitoring of odour" [116], released on 29 December 2017 and taking effect on 1 March 2018, and the "Technical specification for olfactory laboratory construction" [117], released on 10 November 2017 and taking effect from that day, in China have been released after finishing the second round of comments in 2015.

The standard of the "Technical specification on environmental monitoring of odour" specifies the layout of sampling locations, odour sampling frequency, sampling methods, pre-treatment of collected odour samples, odour analysis methods, data processing and reporting, quality control and quality assurance, and so on. The odour sampling methods include sampling by vacuum bottles and sampling bags. The odour sampling and analysis should follow the standard method for odour concentration determination, GB/T 14675 [110], by applying the "triangle odour bag method".

The standard of the "Technical specifications for olfactory laboratory construction" also specifies the olfactory laboratory site selection and layout, interior design of the laboratory, etc. The olfactory laboratory should have at least three functioning areas, including a sampling preparation room, a sample mixing room, and an evaluation room, with two optional functioning areas of a buffer room and a restroom. The site selected for the olfactometric laboratory construction should have a maximum odour concentration of the ambient air lower than 10 ou.

4.3. Odour Impact Assessment in Hong Kong

Odour assessment criteria for Hong Kong can be found on the Hong Kong Environmental Protection Department's website. In Hong Kong, odour is assessed at a 5-s averaging period due to the shorter exposure period tolerable by human receptors. Conversion of model computed hourly average results to 5-s values is necessary to enable comparison against the recommended Hong Kong standard. The hourly concentration is first converted to a 3-min average value according to a power law relationship, which is stability-dependent due to the statistical nature of atmospheric turbulence. Another conversion factor (10 for unstable conditions and 5 for neutral to stable conditions) is then applied to convert the 3-min average to a 5-s average. In summary, to convert the hourly results to 5-s averages, the following factors listed in Table 25 need to be applied:

Table 25. Conversion factors to convert the 3-min odour concentrations to 5-s [118].

Stability Category	1-h to 5-s Conversion Factor
A and B	45
C	27
D	9

The values presented are similar to the peak-to-mean value approach applied in New South Wales.

Under "D" class stability, the 5-s concentration is approximately ten times the hourly average result. Note, however, that the combined use of such conversion factors together with the ISCST results may not be suitable for assessing the extreme close-up impacts of odour sources.

5. Japan

Japan has more than 40 years of odour legislation history at the national level. With industrial development and urbanisation in the 1960s, complaints against environmental pollution, including odours, drastically increased. To take measures against odour issues, the Offensive Odour Control Law (OOCL) [119] was enacted in 1971 and enforced in 1972. It regulates odours emitted from business activities and promotes preventive measures against odours to preserve the living environment and protect the health of the people [120]. Figure 4 depicts the framework of the OOCL.

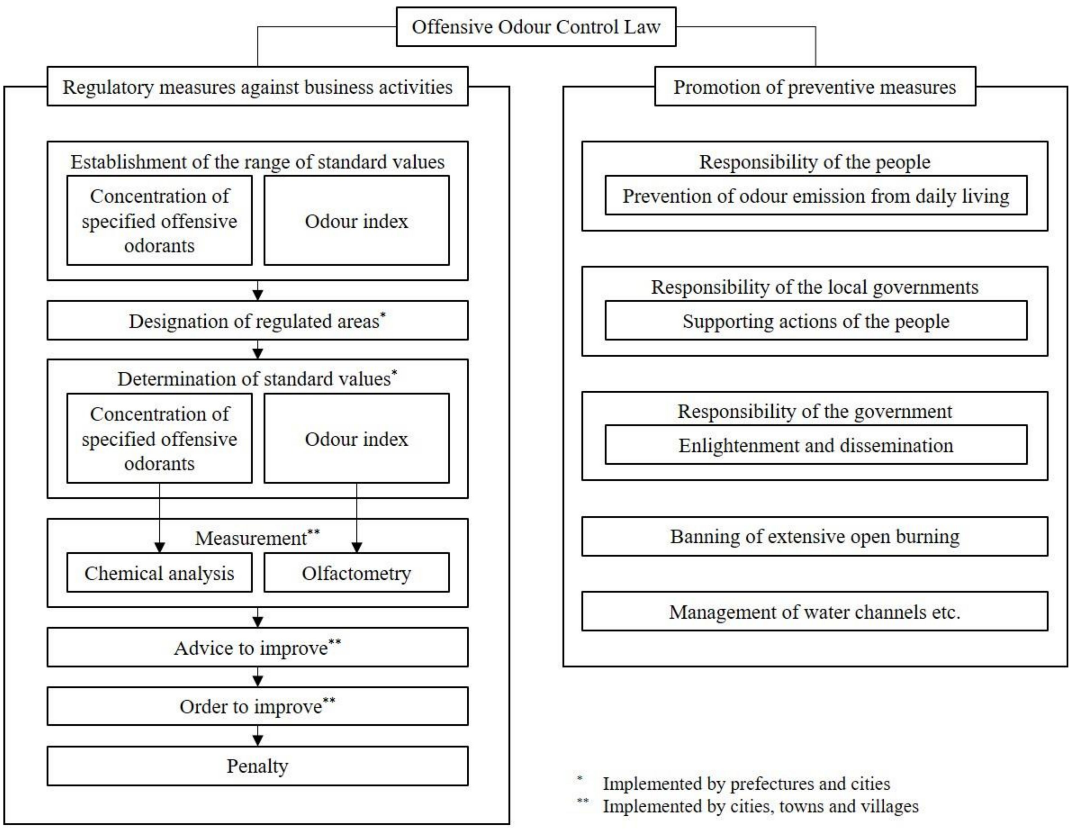

Figure 4. The framework of the Offensive Odour Control Law (OOCL) in Japan [119].

The OOCL provides three types of regulation standards on odours: (1) at the property line of the site, (2) discharged from stacks or other gas emission facilities, and (3) discharged from wastewaters.

Local authorities designate regulated areas in consideration of geographical and demographical conditions. Any kind of activity at factories or other businesses, including livestock farming within the regulated area, comes under odour legislation. Local authorities are entitled to demand reports and conduct on-site inspections at odour-emitting facilities, whereas they should carry out odour measurements by chemical analysis or olfactometry. If an odour-emitting facility in the regulated area does not meet the standard and simultaneously the living environment is impaired, the facility can be advised by the local authority to improve the operating conditions and take preventive measures. If the odour emission remains unchanged, the facility can be ordered to improve the situation. Penalties can be imposed on violators.

When the OOCL was enacted, odour regulations based on the concentrations of odourous compounds were introduced. Up to the present, twenty-two (22) substances shown in Table 26 have been designated as "specified offensive odourants". Local authorities determine the regulation standard values at the property line for each substance within a range established by the government (Table 26), considering the land use, geographical conditions, odour characteristics, and people's sensitivity to odours.

Table 26. Specified offensive odourants and the range of regulation standard values at the property line [119]. Names are formatted to the "IUPAC (common name)" convention.

Specified Offensive Odourant	Range of Standard Value at the Property Line (ppm)
Azane (Ammonia)	1–5
Methanethiol (Methyl mercaptan)	0.002–0.01
Sulfane (Hydrogen sulfide)	0.02–0.2
Methylsulfanylmethane (Dimethyl sulfide)	0.01–0.2
(Methyldisulfanyl) methane (Dimethyl disulfide)	0.009–0.1
N,*N*-dimethylmethanamine (Trimethylamine)	0.005–0.07
Acetaldehyde	0.05–0.5
Propanal (Propionaldehyde)	0.05–0.5
Butanal (Butyraldehyde)	0.009–0.08
2-methylpropanal (Isobutyraldehyde)	0.02–0.2
Pentanal (Valeraldehyde)	0.009–0.05
3-methylbutanal (Isovaleraldehyde)	0.003–0.01
2-methylpropan-1-ol (Isobutyl alcohol)	0.9–20
Ethyl acetate	3–20
4-methylpentan-2-one (Methyl isobutyl ketone)	1–6
Toluene	10–60
Styrene	0.4–2
Xylene	1–5
Propionic acid	0.03–0.2
Butanoic acid (Butyric acid)	0.001–0.006
Pentanoic acid (Valeric acid)	0.0009–0.004
3-methylbutanoic acid (Isovaleric acid)	0.001–0.01

However, these regulations are insufficient to deal with a considerable number of odour complaints caused by unregulated substances or complex odours since odour complaints have become more diversified. To improve this situation, the OOCL was amended in 1995, and odour regulations based on an "odour index", a sensory index of odour determined by the triangular odour bag method (TOBM), was introduced [121]. The TOBM is a static air dilution method by which the odour concentration or odour index is determined. In this method, an odour concentration is considered to be the dilution ratio when odourous air is diluted by odour-free air in an odour bag until the odour becomes unperceivable. The odour index is considered to be a logarithm of odour concentration, multiplied by ten.

The TOBM was first developed by the Tokyo metropolitan government in 1972 [122,123] and notified by the Japan Environment Agency in 1995. Since odour measurement is a crucial element of odour management and regulation, a quality control manual on the TOBM for laboratory use was published in 2002 to develop a reliable odour measurement method [124]. Local authorities determine the odour index standard values within a range from 10 to 21 established by the government. After the amendment of the OOCL, local authorities became entitled to choose either of the two regulations: (1) based on the concentrations of odourants, or (2) based on the odour index. According to the OOCL, the range of the regulation standards of both the concentrations of odourants and the odour index at the site's property line is equivalent to an odour intensity, which ranges from 2.5 to 3.5 on the six-point odour intensity scale shown in Table 27.

Table 27. Six-point odour intensity scale [119].

Scale	Odour Intensity
0	No odour
1	Barely perceivable (Detection threshold)
2	Faint but identifiable (Recognition threshold)
3	Easily perceivable
4	Strong
5	Extremely strong

Odours discharged from stacks and other gas emission facilities are regulated based on the standards at the site's property line. Table 28 summarises three types of odour regulation standards in Japan. Regulation standard values for odours discharged from smokestacks or other gas emission facilities are determined by dispersion modelling. The odour index of the wastewater is determined by the triangular odour flask method (TOFM) [121]. Odour emission facilities should meet all types of regulatory standards.

In addition to odour legislation at the national level, various investigations on chemical analysis and sensory measurement of odours have been carried out by local authorities since the 1960s. Up to the present, more than thirty local authorities have adopted their own odour legislation system as ordinances or guidelines. Moreover, several industrial cities have an agreement with local factories to preserve items such as air, water, noise, vibration, odour, hazardous substances, waste, and greenhouse gases. Based on the agreement, the factories voluntarily meet the desired odour index values, which are more rigid than the regulation standards at odour-emitting facilities. Some cities have also been conducting on-site inspections of potential odour-emitting facilities. These measurement results are released electronically on the city website [125].

Table 28. Summary of three types of odour regulation standards in Japan [121,122].

Regulation Type	Regulation Standard of the Concentration of Specified Offensive Odourants	Regulation Standard of Odour Index
Odours at the property line of the site	(Enforced in 1972) Determined by the local authority within a range shown in Table 26.	(Enforced in 1996) Determined by the local authority within a range from 10 to 21.
(2) Odours discharged from smokestacks or other gas emission facilities	(Enforced in 1972) Given as a flow rate calculated by the following equation: $q = 0.108\ H_e^2\ C_m$ where q: flow rate of specified offensive odourant (Nm^3/h), H_e: effective stack height (m), C_m: standard regulation value of specified offensive odourant at the property line (ppm). Applicable to the following 13 specified offensive odourants. Ammonia Hydrogen sulfide Trimethylamine Propionaldehyde Butyraldehyde Isobutyraldehyde Valeraldehyde Isovaleraldehyde Isobutyl alcohol Ethyl acetate Methyl isobutyl ketone Toluene Xylene	(Enforced in 1999) In the case the stack height (H_o) is 15 m or more Given as an odour emission rate (OER) calculated by the following equation: $q_t = (60 \times 10^A)/F_{max}$ $A = (L/10) - 0.2255$ where q_t: OER of discharged gas ($Nm^3 \cdot min^{-1}$), F_{max}: calculated value using the dispersion modelling in consideration of the building height in the vicinity ($s \cdot Nm^{-3}$), L: standard regulation value of odour index at the property line. (2) In the case H_o is less than 15 m Given as an odour index calculated by the following equation: $I = 10 \log C$ $C = K\ H_b^2 \times 10^B$ $B = L/10$ where I: odour index of discharged gas, K: coefficient determined depending on the stack diameter, H_b: maximum building height in the vicinity (m).
(3) Odours included in wastewater	(Enforced in 1995) Given as a concentration in the wastewater calculated by the following equation: $C_{Lm} = k\ C_m$ where C_{Lm}: concentration of specified offensive odourant in wastewater ($mg \cdot L^{-1}$), k: coefficient shown in Table 29 ($mg \cdot L^{-1}$). Applicable to the following four specified offensive odourants. Methyl mercaptan Hydrogen sulfide Dimethyl sulfide Dimethyl disulfide	(Enforced in 2001) Given as an odour index calculated by the following equation: $I_W = L + 16$ where I_W: odour index of wastewater.

Table 29. Coefficients used to calculate the standard values of specified offensive odourants in wastewater ($mg \cdot L^{-1}$) [121]. Names are formatted to the "IUPAC (common name)" convention.

Flow Rate of Wastewater: Q ($m^3 \cdot s^{-1}$)	$Q \leq 0.001$	$0.001 < Q \leq 0.1$	$Q > 0.1$
Methanethiol (Methyl mercaptan)	16	3.4	0.71
Sulfane (Hydrogen sulfide)	5.6	1.2	0.26
Methylsulfanylmethane (Dimethyl sulfide)	32	6.9	1.4
(Methyldisulfanyl)methane (Dimethyl disulfide)	63	14	2.9

6. United States of America

In the United States, the Environmental Protection Agency (EPA) does not regulate odour as a pollutant; therefore, states and local jurisdictions have attempted to regulate odours. For the individual states, statutes approved by the legislature provide the legal framework for addressing odour emissions, while the corresponding state departments (e.g., Department of Environmental Quality, Department of Natural Resources) are responsible for enforcement of the odour rules or regulations. In the absence of "odour laws" or odour regulations, citizens and communities often find remedies and relief in basic "common law" nuisance lawsuits. However, exclusions and exemptions, such as "right-to-farm" laws and vague definitions of "nuisance", can sometimes make nuisance actions difficult and expensive to prosecute.

The National Air Pollution Control Administration of the U.S. Public Health Service commissioned the Copley International Corporation in 1970 to conduct a "National Survey of the Odor Problem". The Copley study's technical phase found the "dilution-to-threshold (D/T) ambient odour measurement method", embodied in the Scentometer device, to be a utilitarian and effective tool for investigation of odour and that odour judgment panels provide a definitive description of the odour emission [126].

Historically, the D/T values are based on the dilution ratio of the carbon-filtered air volume to the odourous air volume. This is different from laboratory olfactometry, where the dilution ratio is the total volume of air to the odourous air sample volume. The units of D/T are commonly used to specify the threshold value as being determined by field olfactometry and not laboratory olfactometry ($ou_E \cdot m^{-3}$). The difference in dilution ratio calculation provides a relationship of [threshold value in D/T] + 1 = (value in $ou_E \cdot m^{-3}$ or in ou). Examples include 7 D/T being the same as 8 $ou_E \cdot m^{-3}$ (8 ou) or 60 D/T being the same as 61 $ou_E \cdot m^{-3}$ (61 ou). The difference is negligible at relatively low threshold values.

The U.S. EPA commissioned a second Copley study in 1971, "Social & Economic Impacts of Odors", in the United States. The second Copley study found the Scentometer (D/T method) to be an effective and sensitive device and found odour judgment panels were a logistical challenge for responding to all complaints [127].

The U.S. EPA commissioned a third Copley study in 1972 for the "Development and Evaluation of a Model Odor Control Ordinance". The third Copley study recommended that odour regulation and enforcement be relegated to states and local jurisdiction using scientific approaches with trained inspectors using the Scentometer D/T method as well as source odour sampling [128]. This set the course in the U.S. for the EPA to pass jurisdiction of odours to individual states and municipalities.

Prior to these studies, in 1958, 1959, and 1960, the U.S. Public Health Service sponsored the development of an instrument and procedure for field olfactometry (ambient odour strength measurement) through official project grants [129]. The first field olfactometer device, called the Scentometer, was manufactured by the Barnebey-Cheney Company and subsequently manufactured by the Barnebey Sutcliffe Corporation. The only other field olfactometer, recognised by states as equivalent to the Scentometer, is the Nasal Ranger introduced by St. Croix Sensory in 2002.

6.1. State Regulations

As of 2018, field olfactometry still stands as the most commonly utilised method for odour regulation. Ten states currently utilise a D/T field olfactometry limit for their odour regulation: (1) Colorado [130], (2) Connecticut [131], (3) Delaware [132], (4) Illinois [133], (5) Kentucky [134], (6) Missouri [135], (7) Nevada [136], (8) North Dakota [137], (9) West Virginia [138], and (10) Wyoming [139]. Figure 5 displays the U.S. states with odour regulations. The ten field olfactometer states are displayed in red. Based on the original field olfactometer studies, most of these states have an odour limit of 7 D/T. As an example, Regulation 2 (5 CCR 1001-4) from the State of Colorado: " ... areas predominantly for residential or commercial purposes, it is a violation if odours are detected after the odourous air has been diluted with seven (7) or more volumes of odour-free air (7-D/T)" [130]. The Colorado regulation also designates a higher limit (15-D/T) for other land use areas, i.e., industrial. However, Colorado limits ambient odour to only 2 D/T at the receptor near large pig facilities. Once an enforcement agency within the state, such as the city of Denver, receives citizen complaints, enforcement personnel respond to the complaint location(s) and measure the D/T with field olfactometry every 10 min for 1 h. A violation exists if the enforcement agent twice measures the odour at 7 D/T or higher, with these measurements separated by at least 15 min, i.e., there is an odour above the limit with a duration/frequency.

Figure 5. States of the U.S. where odour regulations exist based on dilution-to-threshold (D/T), indicated in red. The blue states have regulations with some reference to odour impacts [130–141].

Figure 5 also displays five states in blue, which have odour nuisance regulations with specific reference to odour properties, but without specific criteria for odour measurement or determination of nuisance. In 2013, and later updated in 2014, the Oregon Department of Environmental Quality (DEQ) published a document titled "Nuisance Odor Strategy" [140], which defines actions by the state for facilities under scrutiny for violating the Oregon nuisance code: " . . . may not generate odours that cause an unreasonable interference with another's enjoyment of their property" [141]. When complaints are issued to the DEQ, a facility is reviewed and prioritised based on a two-part nuisance score. One part is rated based on the frequency and duration of the odours, and a second value is based on the strength and offensiveness. An "Odor Intensity Referencing Scale" [8] is suggested for determining odour strength but not required by the nuisance law. Evidence is provided to a nuisance panel. If the panel issues notice of a nuisance, then a facility will be required to enter into a best work practices agreement and a complete a nuisance abatement proposal. While this is a detailed process, the determination of odour strength and offensiveness remains up to the subjective decision of an inspector.

6.2. Municipalities

Numerous municipalities in the U.S. have chosen to regulate odours when their state has not. One example of a U.S. municipal odour ordinance is from the city of Independence, Louisiana. Five stipulations of the Independence odour ordinance are as follows: (1) unlawful to cause emissions of an odour nuisance or odourous air contaminant, (2) odour that is unreasonably unpleasant, distasteful, disturbing, nauseating, or harmful to a person of ordinary sensibilities and which is detectable after it is diluted with seven volumes of odour-free air by a field olfactometer, 7 D/T, (3) the city may issue a citation for the violation, (4) any person may file a complaint, and the city will investigate the complaint, and (5) USD 500 penalty on conviction; penalty does not preclude further actions to abate violations. The use of the phrase " . . . to a person of ordinary sensibilities . . . " is commonly used in municipal codes for defining a nuisance; however, this remains arguable without a measurable parameter.

The second example of a U.S. municipal odour ordinance is from the city of Des Moines, Iowa. Des Moines code enforcement officers respond to citizen complaints as part of their normal code enforcement duties, i.e., restaurant inspections [142]. The city declares an "Odor Alert" when they receive ten complaints in a 24-h time period. An inspector responds, measures the ambient odour, identifies the probable source, and serves a notice of violation. A facility that receives three notices of violations in a 90-d period is designated by the city as a "significant odor generator" and is required to submit an "odor management plan" that may include air stack testing and air dispersion modelling. The designated "significant odor source" may appeal to a citizen "Odor Board", then the city council, and then the municipal court. Implemented in 1991, the city of Des Moines' citizen Odor Board is a unique, novel, and effective approach to addressing local odour nuisances.

When citizens find themselves in a position where the federal government, their state government, and their local municipality (or county, parish, district, or similar organisation) have not enacted an odour nuisance ordinance, there is the final option of bringing a "common law" legal suit against the facility. A judge and jury then determine the nuisance based on the evidence presented by the plaintiff and defendant.

6.3. Odour and Agriculture in the USA

Odour and agriculture are one of those "hot button" issues that exist worldwide, yet they have a very specific status in the USA. The Council for Agricultural Science and Technology [143] has published a white paper prepared by scientists from six U.S. universities summarising "Air Issues Associated with Animal Agriculture: A North American Perspective". In that study, odour emissions were discussed in the larger scope of gaseous and particulate emissions from pig, poultry, beef, and dairy production. While odour is mainly a local issue, hazardous gases (e.g., NH_3 and H_2S, some volatile organic compounds; VOCs) are regional and national concerns.

The CAST [143] argues for a "common sense" approach to regulating gaseous (including odour) emissions that recognises regulatory needs and market forces. All of this process needs to involve the public, regulatory agencies, and the livestock industry. Both the positive (economic development) and negative (e.g., lower real-estate values in the vicinity) aspects of animal production need to be reconciled for the greater good of rural communities.

The livestock industry in the U.S. funds air quality research aimed at baseline emission inventories (e.g., the National Air Emissions Monitoring Study, 2007–2009) [144] and research aimed at developing and field testing promising mitigation technologies. An important part of mitigation research is its practicality in the U.S. socio-economic climate. Economic analysis of tested technologies is a typical requirement for farm testing and possible future adoption.

The livestock industry funds educational tools for farmers, regulatory agencies, and scientists. For example, the Air Management Practices Assessment Tool [145] is an online resource to "provide an objective overview of mitigation practices best suited to address odour, emissions and dust at your livestock operation so that livestock and poultry producers may compare and narrow their options of mitigation techniques". Most recently, a scientific database was added to AMPAT. The scientific database summarises 265 papers reporting on the performance of technologies to mitigate emissions of odour and other gases from animal production operations [146,147]. There is growing evidence that some mitigation technologies offset benefits from regulating one pollutant by increasing emissions of another (e.g., NH_3 and N_2O).

Odour emissions are mainly generated by manure handling, storage, treatment, and land application. These processes are highly site-specific. The complexity of odour emissions is confounded by many factors at the nexus of species, local climate, geography, size and type of the facility, animal diet, manure management system, ventilation system, regulations, and human factors.

Many animal production facilities operate in areas that have a non-attainment status for regulated air pollutants, and thus face larger scrutiny because of the non-attainment of the air quality standard of the whole area (e.g., St. Joaquin Valley in California). Some regulated air pollutants associated with animal agriculture (e.g., PM-10, PM-2.5 [148]) are regulated by the National Ambient Air Quality Standards. Others (e.g., NH_3) are of concern due to the formation of secondary fine PM-2.5 and eutrophication. Many odourous gases are classified as VOCs, some reactive, and thus are of interest to ozone and NOx management.

The last thorough review of odour regulations focusing on U.S. agriculture was published by Redwine and Lacey (2000) [149]. Most states define a regulatory approach to confined animal feeding operations (CAFOs) based on the number of animal units (AU). Animal units are typically defined as 500 kg of live weight. Redwine and Lacey (2000) [149] summarised odour regulations in all U.S. states and grouped them according to the following criteria:

- Odour—Is there direct regulation of odour emissions?
- Setbacks—Are there setbacks (i.e., mandatory distances to neighbours)?
- Permits—Are permits required?
- Public—Is there public involvement in the permitting process?
- Training—Is some form of training required?
- LA—Are there land application [of manure] restrictions?
- Other—Any other approach to regulating odour from CAFOs or related
- information.

To date, the Redwine and Lacey report (2000) [149] is still the most comprehensive resource on odour regulations and animal agriculture in the US. They have summarised the following main points: 10 U.S. states regulate odour directly and 34 U.S. states have some rules or regulations designed to curtail odour emissions without explicit limitation (e.g., distance setback, manure management plan, permitting, land application regulations, manure application training).

As the U.S. Environmental Protection Agency (EPA) and state regulatory agencies are increasing monitoring of animal production operations, the emissions of odour and technologies to comprehensively mitigate them will become more important.

The U.S. EPA is also considering the application and possible implication of the existing CERLA/EPCRA ruling limiting emissions of any substance to air at or above 100 lbs (~45 kg) per day, per site.

7. Canada

Canadian federal legislation does not cover any odour regulations from industrial or agricultural facilities. Individual provinces and territories have an obligation for odour regulations [150,151]. In legislation, odour can be defined in different ways, such as a pollutant, contaminant, type of substance, nuisance, or an odourous substance and odourous contaminant. An odour may also be defined by its effects, which include being a contaminant that causes an adverse effect. The following is a brief summary of how odour is regulated by individual provinces in Canada [152].

7.1. Alberta

The Alberta Environmental Protection and Enhancement Act (EPEA) describes that an "adverse effect" means impairment of or damage to the environment, human health and safety, or property. In addition, the EPEA describes a "substance" as any matter that is capable of becoming dispersed in the environment or is capable of becoming transformed in the environment into matter. There is no specific mention of odour in the EPEA as a substance, which causes an adverse effect. However, odour might be a dispensed substance in the environment and, therefore, could be a prohibited contaminant.

7.2. British Columbia

In British Columbia, the Environmental Management Act does not mention odour; however, odour can be treated as an air contaminant that interferes with normal conduct of business or causes physical discomfort to a person. Odours attributed to any agricultural operations or activities on a farm in accordance with the Agricultural Waste Control Regulation, Code of Agricultural Practice for Waste Management are not prohibited.

7.3. Newfoundland and Labrador, Northwest Territories, Prince Edward Island

In Newfoundland and Labrador, the Northwest Territories, and Prince Edward Island, there are no standards for odours; however, odour is a prohibited contaminant [153]. In Newfoundland and Labrador, the Air Pollution Control Regulation 39/04, under Air Quality Standards-Schedule A, includes prescribed air quality standards which are relevant to agricultural operations for NH_3 (100 g·m^{-3} as 24-h average), H_2S (15 g·m^{-3} as 1-h standard, 5 g·m^{-3} as 24-h standard), and reduced sulfur compounds (30 g·m^{-3} as 1-h standard), expressed as an equivalent amount of H_2S.

In Prince Edward Island, under the Environmental Protection Act, odour is a contaminant; however, there is no standard for odour [154].

7.4. Nova Scotia and Saskatchewan

Under the Environmental Act, there is no odour standard in these provinces, but odour can be a contaminant [155].

7.5. Manitoba

In Manitoba, under the Environmental Act, odour is a pollutant, and there are some guidelines for odour concentrations in the ambient air with a maximum of two odour units for a residential area, a maximum of seven odour units for an industrial area, and one odour unit for all areas. The guideline states that to determine these concentrations, duplicate odour measurements should be taken not less than 15 min apart and not more than 60 min apart. The measurements are based on the ambient level. There are also some criteria for a maximum ammonia concentration of 1.4 μg·m^{-3}, and a maximum H_2S concentration of 15 μg·m^{-3} averaged over 1 h or 5 μg·m^{-3} averaged over 24 h [156].

7.6. Ontario

In Ontario, under the Environmental Protection Act (EPA), odour is a contaminant. Odour is a contaminant to the degree that it may cause discomfort, loss of enjoyment of normal use of the property, or interfere with the normal conduct of business. Another section of the act prescribes the maximum point of impingement concentrations for a variety of compounds [157]. A number of these are based on the odour potential of these compounds. Dispersion models are included in the regulation for calculating the maximum point of impingement concentrations from emission rate data [158]. Odour issues are routinely addressed by the Environmental Compliance Approval (ECA). Requirements for odour emission tests are often included as conditions for industrial sources, which are judged by the Ontario Ministry of the Environment, Conservation and Parks (MECP) to have a potential for odour impact. Emission test results are used with regulatory dispersion models to estimate the maximum point of impingement odour levels. A guideline of 1 ou odour concentration is based on the model's prediction when a 10-min averaging time is used [159].

However, the EPA does not apply to animal wastes disposed of in accordance with both normal farming practices and the regulations made under the Nutrient Management Act, 2002 [160].

The Ontario Municipal Act 2001 [161] allows municipalities to control odours within their jurisdiction. If the ministry receives an odour complaint, it is the role of the district office to follow-up the complaint, to verify the information provided, and to make an assessment on whether further action is required by the ministry. If the odour is deemed to be causing any adverse effects, steps will be taken to identify the source of the odour, address any adverse effects caused by the odour, and ensure that the responsible party takes all reasonable steps to mitigate the odour.

7.7. Quebec

In Quebec, odour is a contaminant under the Environmental Quality Act [162]. There are some odour standards for specific facilities, such as standards for odours discharged by a fried food plant or coffee roasting plant.

There is also an ambient air quality standard for H_2S—14 $\mu g \cdot m^{-3}$ averaged over 1 h. However, there is no standard for NH_3.

7.8. Examples on How to Deal with Odour Complaints

As an example, in Ontario, when odours are detected, complaints may occur. The complainants can contact the MECP, or they can complain directly to the facility "in question". The environmental officer investigates the odour episode and very often conducts a site visit to the area. During regular business hours, the local district office can be contacted directly; outside normal business hours, calls are directed to the ministry's Spills Action Centre toll-free line [163].

If the odour complaints are persistent for the area, the MECP can order the facility to perform an odour assessment, including odour testing, and, if the odour limit is exceeded, the facility is required to provide a plan of controlling measures.

7.9. Odour Assessments

There is no standard method across Canada for odour assessments; however, the most common approach is source odour measurements with dispersion modelling to predict off-site odour concentrations at any sensitive receptor [164]. Odour assessments are generally performed for the following reasons: to verify and investigate odour complaints; to determine the off-site odour impact from existing, expanding, or new operations; to assess long-term odour levels in an area; to determine compliance with odour legislation, or to rank potential odour sources for mitigation purposes.

In addition to source odour testing, an ambient odour assessment can be performed, which in most cases includes ambient testing at the affected or complained areas using a standard procedure and dynamic olfactometry evaluations using screened panellists. Further, ambient odour assessments may include community/resident odour surveys, odour observations, and observation forms for residents. Ontario is the strictest province in terms of odour regulations.

Odour testing in Ontario is performed according to Ontario's MECP Source Testing Code, Method ON-6: Determination of Odour Emissions from Stationary Sources [165]. The odour analyses follow the same method, which is similar to EN13725 with some exceptions, such as odour analysis only being conducted once and with eight panellists.

8. South America

There is a wide diversity of legislation related to odour management in the countries of Latin America. In this section, some countries that have developed legislation in terms of odour management are detailed.

8.1. Chile

Despite many disastrous socio-environmental conflicts triggered by odour episodes, Chile has not yet developed an odour regulation. The air pollution legislation has almost no specific standard for odours or compounds related to them, except the standard of total reduced sulfur odour generators associated with the manufacture of sulfated pulp [166].

The second body of law is the Law on General Environmental Framework [167] whose main instruments include environmental quality standards, emission standards, and the system of environmental impact assessment (SEIA). Regarding the existing environmental quality standards, there is no specific standard for odours in ambient air. There are ordinances in some municipalities, which establish restrictions on the generation of odours that may be a health risk or be annoying to the community [168].

As for the legal tools available to manage odours in the country, there is the Sanitary Code, which gives jurisdiction to the Health Authority (formed by the Ministry of Health and its Regional Ministerial Secretariats of Health) to issue general, or specific, provisions for the proper performance of the code, conferring the duty to monitor odour emissions and use sanctions such as fines, closures, cancellation of operating licenses or permits, or even closing facilities depending on the number of infractions. There is the use of an offensive odour indicator parameter, which is the number of complaints or allegations made by the community to the Health Authority or other agencies (Seremi, municipalities, etc.) which are channeled through the Health Authority.

In 2014, after a conflict caused by pig production, the Ministry of Environment (MMA) began developing a Strategy for Odour Management in Chile [169]. This aim was to strengthen the regulatory framework through short-, medium-, and long-term measures in order to help to quantify, control, and prevent odour generation. In this regard, the Ministry of the Environment is developing a "Regulation on Odour Prevention and Control" which may help some industrial sectors potentially generating odours to adopt improvements or technologies and practices to control odour.

The standardisation of odour measurement methodologies was also needed. To date, the standards homologated in Chile by the National Institute of Normalization (INN) are:

NCh3387:2015: Air Quality Assessment of Odour Annoyance Survey [170];

NCh3386:2015: Air Quality—Static sampling for olfactometry [171]; reference to German standard VDI 3883 Part 1:2015 [172];

NCh3190:2010: Air Quality—Determination of odour concentration by dynamic olfactometry [173]; reference to German standard VDI 3880:2011 [2] and European standard EN 13725:2003 [1].

In regulatory terms, as part of the Strategy for Odour Management, MMA establishes a prioritisation of these potential odour-generating activities based on the following criteria:

(1) Activities with a greater number of complaints.
(2) Activities with a greater number of facilities.
(3) Activities involved in socio-environmental conflicts due to odours.

In November 2018, the draft standard for the emission of pollutants in pig farms was initiated and was expected to enter into force in 2020.

In 2019, a draft applying to the fishing industry was started, and it will be in effect in 2021.

It follows the beginning of the emission standard for wastewater treatment plants to end this stage with the cellulose industry and landfills.

8.2. Colombia

In Colombia, in recent years, there have been some interesting movements in odour regulation. The toolset for odour management has exponentially grown to a scale similar to that of many advanced European countries.

Although, in 1994, the regulation of the protection and control of air quality already established some restrictions and prohibitions related to emissions and the places that generate offensive odours, there has been a relevant advancement in the development of odour regulation in the last 6 years.

The first step was given in 2011. The Colombian Technical Norm NTC 5880 [174], "Air Quality. Determination of Odour Concentration by Dynamic Olfactometry", was published in December 2011. This norm defines a method for the objective determination of an odour concentration of a gas sample through dynamic olfactometry. EN 13725 was used as a reference document for this norm.

Some other norms related to odour measurement were published in 2013, such as the Colombian Technical Standard NTC 6011 [175], "Static Sampling for Dynamic Olfactometry"; the standard NTC 6012-1 [176] about the "Effects and Assessment of Odours. Psychometric Assessment of Odour Annoyance. Questionnaires"; or the standard NTC

6012-2 [177] about the "Effects and Assessment of Odours. Determination of Annoyance Parameters by Questioning; Repeated Brief Questioning of Neighbour Panellists".

In 2013, the Colombian Ministry of Environment and Sustainable Development approved Resolution 1541 [178] that sets acceptable levels for odours and some odourants in ambient air. This resolution also developed the procedures for activities of potential producers of odour complaints. It constitutes, in the first instance, an instrument for the promotion of the inclusion of good environmental practices considering that a process or a part of a process or activity causes an odour emission.

In t2014, further standards were published, such as the Colombian Standard NTC 6049-1 [179], "Measurement of Odour Impact by Field Inspection. Grid Measurement", the standard NTC 6049-2 [180], "Measurement of Odour Impact by Field Inspection. Plume Measurement", the NTC 6049-3 [181], "Measurement of Odour Impact by Field Inspection. Determination of Odour Intensity and Hedonic Tone", and, finally, the NTC 6049-4 [182], "Determination of the Hedonic Odour Tone Polarity Profiles".

The implementation of the regulatory scheme is focused on improving the process and activities' environmental performance, understanding that one of the main effects of the use of good environmental practices is the prevention, mitigation, and control of environmental impacts. In that sense, this resolution includes the plan for the reduction in the offensive odours impact—PRIO (because of its acronym in Spanish)—by which the activity or process proposes and puts under assessment and approval of the environmental authority the measures considered suitable for the management of their odour emissions.

Once the environmental authority assesses and approves the PRIO, the activity or productive process must fulfil the goals of this plan in the limited time for doing so and there is continuous surveillance from the environmental authority during the whole time of the activity or process. The implementation of the regulation is described as follows (Figure 6):

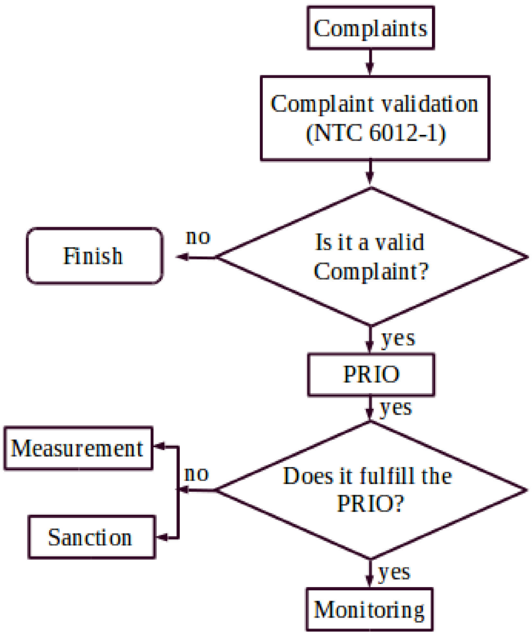

Figure 6. Implementation of Resolution 1541 [178].

The resolution also sets maximum acceptable limits of air quality for odourants substances such as H_2S, total reduced sulfur (TRS), and NH_3, applicable to those cases where these substances are the main ones responsible for odour issues. In Colombia, there are daily limits set for the odourants H_2S, TRS, and NH_3 of 7, 7, and 91 $\mu g \cdot m^{-3}$, respectively, and hourly limits of 30, 40, and 1400 $\mu g \cdot m^{-3}$, respectively.

On the other hand, Resolution 1541 [178] also establishes maximum acceptable limits for air quality in European odour units, so all the activities responsible for odour generation are under the fulfilment of one or another standard (for substances or odours). The following Table 30 shows the different limits in Colombia:

Table 30. Admissible concentration limits for odours in the air [178].

Activity	Admissible Level
Meat, fish, mollusc, and crustacean processing and preservation Oil refinery processes Paper pulp, paper, and cardboard manufacture Leathery and tanning of skins Nonhazardous waste collection, transport, transference, processing, or disposal WWTP Activities that collect water from water bodies receptors of wastewater discharges Manufacture of substances and basic chemical products Thermal destruction of animal by-products	$3\ ou_E \cdot m^{-3}$
Farms Manufacture of vegetable oils and fats	$5\ ou_E \cdot m^{-3}$
Decaffeination, roasting and grinding of coffee Other activities	$7\ ou_E \cdot m^{-3}$

These limits are expressed as the 98th percentile of the hourly mean (equivalent to 175 exceedances per year). The method used to measure odours is detailed in the Colombian norm NTC 5880 [174], “Air Quality. Determination of Odour Concentration by Dynamic Olfactometry”. The dispersion models allowed for odour are AERMOD and CALPUFF.

As mentioned above, the main purpose of the offensive odour regulation is to encourage sound environmental practices in activities or processes so the environmental impact can be managed properly in a comprehensive way, while also increasing the environmental and productive competitiveness.

Resolution 1541 [178] was further developed by Resolution 2087 [183], “Protocol for Monitoring, Control, and Surveillance of Offensive Odours”. This resolution defines the methods, criteria, and suitable specifications for measurement of odourant substances or odours as well as the development of the PRIO.

9. Discussion

Odour is based on perception, the chemosensory response to odourants in the air. We experience odours throughout our days around the home and in our communities. The degree of an odour impact is based on five main factors, including the offensiveness and intensity/concentration of the odours, the frequency, and duration that the odours are present, and the location or context of the experience, all together commonly referred to as FIDOR (frequency, intensity, duration, offensiveness, and “receptor”, which is also labelled as “location” in the alternative FIDOL). The personal experience and biases of the affected citizens have historically complicated the assessment by enforcement officials; however, standardised laboratory and field-based odour assessment protocols have provided the means to quantify a largely subjective experience objectively.

The complex interaction of the five FIDOR elements of odour makes it challenging to “regulate” odours at a country-level. Different philosophies of control, as well as different regulatory systems, hinder the development of one common approach to policy. However, utilising various quantification methods, several countries and provinces/states have adopted approaches that are suitable or politically feasible to legislate and enforce community odours.

The regulatory approaches outlined throughout this paper provide a foundation for highlighting important elements of regulation. Below is a list of questions that may be used for a discussion involving the formulation of odour regulation. This list is not complete, but it is an outline that can be useful.

Planning:

I. How do the existing local planning and zoning policies impact the proposed regulation and its implementation?
II. Who should be the stakeholders involved in drafting an odour regulation?
III. What are the costs of regulation (to the facility and the community/agency)?
IV. What are the costs of no regulation (to the facility and the community/agency)?
V. Choice of regulatory criteria:
VI. In which cases is an air quality regulation suggested, and in which cases is an emission regulation better?
VII. Why are only some industries regulated and not necessarily all types of emissions in a region or country?

Continuous improvement:

I. Which level of graduality has been reached by countries with a history of odour regulations, and what were the results?
II. Metrics:
III. What are the indicators of a successful odour regulation?
IV. How have various methods of current and past regulation been successful?
V. Is there a link between regulation and accreditation (operating permit, obligatory periodic audit)?

Recommendations:

I. Is there a list of common recommendations to countries/stakeholders that are considering an odour regulation?
II. Is there a need for a "clearinghouse" of best practices that document country-level experiences?
III. It is a challenge to answer these questions, and could the answers be different depending on the local/state situation.

For most of them, there is not one univocal answer. This paper describes approaches to the different regulations adopted by selected countries and regions within the countries. Table 31 summarises approaches categorised by methods, countries where they are adopted, and related pros/cons. Note that the identification of countries is based on the existence of regulatory enforcement. In some cases, an approach may still exist in a specific country based on specific facility permits. For example, while countries such as the USA or Spain may not regulate an odour concentration source emission measurement, a facility permit may be used to instill specific enforcement on one facility.

Monitoring emissions or rates of emission at the source, either perceived odours or chemical odourants, is a relatively simple approach, but it has the limitation that it does not account for the people's exposure and perception downwind.

Chemical analysis for the measurement of odourant concentrations has a lower uncertainty, but it is not always possible to relate chemical composition to odour perception. More research is needed to link specific chemicals with their influence on the overall odour. Chemical analysis alone can miss the impact of strong odourants that are present at low concentrations. Here, the use of an odour activity value (OAV) could be useful, but more data are needed on detection threshold values for important odourants.

Separation distances can be effective in preventing odour problems. However, more research is needed to improve models and/or adopt industrial models for odour regulations.

Table 31. Examples of approaches to odour regulations in selected countries [1,173,174,184–187].

General Approach	Methods	Country	Pros	Cons
(1) Emission measurement	(a) Measurement of odour concentration at the source of emissions	Japan (Measurement of odour index), China, Colombia, Canada (Quebec), Germany, UK	Standardised methodology (1)	No direct relationship with odour perception by citizens
	(b) Measurement of odour emission rate (at the source of emissions)	Japan, Canada, Germany, UK	Standardised methodology (1) for point sources and active area sources; More related to odour perception than just odour concentration measurement	Not standardised for passive area sources (except for Germany) Hardly achievable in the case of diffuse sources Not applicable to sources with variable emissions over time No direct relationship with odour perception by citizens (meteorological conditions and distance to receptors not considered)
	(c) Measurement of the concentration of specific odourants (chemical concentrations, mass/volume, volumetric mixing ratios)	USA (e.g., H_2S), Spain, Canada, Australia, New Zealand	High confidence level in the technique	Not representative of the odour of mixture. No direct relationship with odour perception by citizens
	(d) Measurement of the emission rate of specific odourants (chemical mass/time)	Japan, Canada, China	Standardised methodology	Not representative of the odour of mixture. No direct relationship with odour perception by citizens
(2) Fenceline measurement	(a) Measurement of odour index at the property line	Japan, China	Standardised methodology (Japan Environment Agency Notification No.63: 1995) Direct relationship with odour perception by citizens	
	(b) Measurement of the concentration of specific odourants at the property line	Japan, Canada, China	Standardised methodology (2)	Not representative of the odour of mixture. No direct relationship with odour perception by citizens
(3) Limitation of Impact	(a) Separation distances defined based on dispersion modelling			Only applicable to new installations. No direct relationship with odour perception by citizens
	(b) Separation distances defined based on empirical equations	USA, Canada (animal agriculture) Australia and New Zealand separation distances are defined by modelling and empirical equations	Ease of application (Less complex than dispersion models)	Only applicable to new installations. No direct relationship with odour perception by citizens
(4) Exposure assessment (OIC and complementary approaches (e.g., FIDOR factors))	(a) Dispersion modelling	Italy (Lombardy, Piemonte, Trento), Canada (Ontario), France (applicable for solvent industries), Germany	Applicability for predictive purposes	No standardisation. Different models and settings can be used leading to different results Hardly applicable to complex sources (diffuse or variable over time)

Table 31. *Cont.*

General Approach	Methods	Country	Pros	Cons
	(b) Field inspection	Germany (growing in AU and NZ), UK	Standardised methodology (European standard EN16841) Direct relationship with odour perception by humans	Long duration, limitations in extreme weather conditions, in not accessible areas, unsafe spots
	(c) Field olfactometry	USA (States and Municipalities)		
	(d) Citizen science		In general, less expensive than other techniques (no sophisticated equipment nor trained assessors needed). Not standardised. Bias can be reduced, and the technique can be very effective if relying on a large number of citizens and if observations are validated	Risk of bias due to the prejudice of involved citizens Might be ineffective in very conflictual situations (e.g., lawsuits) Challenging to verify each specific complaint
	(e) Collection of complaints (free-form or structured)	USA (municipalities), Colombia, New Zealand, Australia, UK	Easy to implement	Risk of bias due to the prejudice of involved citizens Might be ineffective in very conflictual situations (e.g., lawsuits) Challenging to verify each specific complaint
	(f) Regulator determination following complaints.	UK, Colombia	No measurements are needed. Regulators need to show permit or consent conditions are not being met	It can end in a court judgment
	(g) IOMS (instrumental odour monitoring systems)	France	Continuous measurement Possibility to discriminate odour/odourant sources	Not standardised technique It should be connected to odour measurements

The most common approaches to odour regulation are those entailing the use of dispersion modelling and field inspections for determining citizens' exposure to odours and compare it with odour impact criteria (OIC). There are two groups of OIC used in various jurisdictions. The first group is common in the Anglo-American countries with high threshold/low exceedance probability; the second group with low threshold/high exceedance is based on investigations in Germany. A more detailed discussion about OIC and their application in different countries in the form of Table S1 is provided in the Supplementary Material. A more comprehensive review of OIC and the manner in which they are applied is summarised by Brancher et al. (2017) [188].

Dispersion models have the advantage that they usually are less time-intensive and cost-intensive than field inspections. On the other hand, field inspections account for the real impact in the community. Field inspections are now regulated at a European level by EN 16841 [3,4].

Another possible approach to be considered for assessing odour impacts and regulating odours is advanced psychometry based on citizen science. Citizen science relies on observations from a large number of citizens. The methodology developed to do so is complex and involves engagement approaches and other aspects such as data plausibility checks and complex meteorological checks. Once this approach is made, there is no risk of personal biases from individual observations as each observation is validated, taking into account different factors. A recent review of assessment techniques in the context of malodour impact on communities was published by Hayes et al. (2014) [189]. Recent work by Braithwaite (2019) [190] proposes the use of the odour profile method for complex or unresolved cases and their sources, which involves an odour wheel, panel assessment of the intensity of the odour, and location information.

Instrumental odour monitoring systems (IOMS) have been developed with a wide range of technologies available. Results from various systems are not easily comparable, making it a challenge to use them for regulation while keeping an open market to allow for all technologies. Efforts have been made to regulate environmental odour monitoring with IOMS, but this is a very challenging and heavily debated task. The only regulation concerning IOMSs is in France. In this country, a plant may decrease the frequency of periodical measurements performed by olfactometry if it has an IOMS.

10. Conclusions

While many countries and regions regulate odours with different approaches, there can be agreement among all involved that the regulation of odours can be an immense problem. Odour regulation is a place where science, policy, economics, and public relations are interconnected.

These odours may be quantified based on odourant concentrations as well as human perception. Objective measurements of the odour experience include laboratory and field assessments with olfactometer devices and by direct observations. Air dispersion models and other computer algorithms, such as setback models, further analyse and quantify odour exposure.

More and more countries and communities are regulating odours, and the trend is bound to continue. There is an overall trend towards the measurement of odours instead of chemical odourants, while efforts to standardise odour concentration measurement and field assessments continue around the world.

There is expected to be an increase in approaches based on citizen science. Technology advancements will continue to make it easier to collect data efficiently and analyse the inputs more rapidly.

There are also promising advancements occurring with the standardisation of electronic noses and the development of more effective measurement tools. Multiple consensus working groups are currently discussing methods for testing and validating chemical sensing technologies.

In the end, integrated approaches are often needed to obtain the broadest vision of odour problems. Methods that can take into account all elements of the FIDOR model will go farthest to balance the interests of key stakeholders. Continual review of the various methods in use will provide lessons for countries and regions, creating new or modifying existing regulations.

Supplementary Materials: The following are available online at https://www.mdpi.com/2073-4433/12/2/206/s1, Table S1: Odour impact criteria (OIC) of various jurisdictions defined by the odour concentration threshold CT* ($ou_E \cdot m^{-3}$) for the corresponding integration time of the ambient concentration and the exceedance probability p_T (in %). The ambient odour concentration is determined either by the integration time or the peak-to-mean factor F.

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Abbreviations

ADMS	Atmospheric Dispersion Modelling System developed by Cambridge Environmental Research Consultants.
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
AMPAT	Air Management Practices Assessment Tool
AUSTAL2000G	Lagrangian odour dispersion model used in Germany
AWAC	Walloon Agency for Air and Climate
BAT	best available technology
BER	built, extended, rebuilt
BPM	best practicable means
CAFOs	confined animal feeding operations
CALPUFF	atmospheric pollution dispersion modelling system
DEFRA	Department for Environment, Food and Rural Affairs (United Kingdom)
DEQ	Department of Environmental Quality (Oregon)
D/T	detection/threshold
EA	Environment Agency (England)
ELV	emission limit value
EN	European Standard identified by a unique reference code "EN"
EPA	Environmental Protection Agency
EPEA	Environmental Protection and Enhancement Act (Alberta)
GRAL	Lagrangian dispersion model.
IMPACT	an odour dispersion model used in Flanders
IOMS	instrumental odour monitoring systems
INN	National Institute of Normalization
LASAT	Lagrangian dispersion model.
MMA	Ministry of the Environment (Chile)
MECP	Ministry of the Environment, Conservation and Parks (Ontario)
NAEMS	National Air Emissions Monitoring Study
NeR	Dutch Emission Guidelines
NIEA	Northern Ireland Environment Agency
NRW	Natural Resource Wales
NTC	Colombian Technical Norm (Colombian Institute of Technical Standards and Certification)
OAV	odour activity value
OIC	odour impact criteria
OOCL	Offensive Odour Control Law (Japan)
ou	American and Australian odour unit
$ou_E \cdot m^{-3}$	odour concentration, European odour unit per cubic metre
PRIO	Plan for the reduction of the offensive odours (Spanish)
SEPA	Scottish Environmental Protection Agency
Su	sniffing unit
TOBM	triangle odour bag method
TOFM	triangle odour flask method
TRS	total reduced sulfur
VDI	Verein Deutscher Ingenieure (VDI) (English: Association of German Engineers)
VOC	volatile organic compound
WWTPS	wastewater treatment plants

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