Chemosphere xxx (2016) 1–40

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Review

A review of odour impact criteria in selected countries around the world

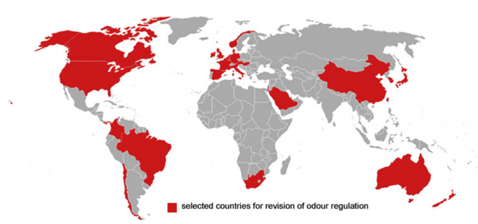
Marlon Brancher [a,*], K. David Griffiths [b], Davide Franco [a], Henrique de Melo Lisboa [a]

[a] Laboratory of Air Quality Control (LCQAr), Department of Sanitary and Environmental Engineering (ENS), Federal University of Santa Catarina (UFSC), 88040-900, Florianópolis, Brazil
[b] School of Veterinary and Life Sciences, Murdoch University, 90 South Street, Murdoch, Western Australia, 6150, Australia

HIGHLIGHTS

- Odour regulations from 28 countries are reviewed.
- Worldwide, odours are regulated by different approaches.
- Limits of odour concentration in ambient air differ substantially among jurisdictions.
- The international regulatory framework on odour impact criteria calculated by dispersion models is summarized.
- An integrated multi-tool strategy for odour impact assessment is recommended.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 July 2016
Received in revised form
28 November 2016
Accepted 30 November 2016
Available online xxx

Handling Editor: R Ebinghaus

Keywords:
Air pollution
Regulation
Odour
Criteria
Dispersion modelling

ABSTRACT

Exposure to environmental odour can result in annoyance, health effects and depreciation of property values. Therefore, many jurisdictions classify odour as an atmospheric pollutant and regulate emissions and/or impacts from odour generating activities at a national, state or municipal level. In this work, a critical review of odour regulations in selected jurisdictions of 28 countries is presented. Individual approaches were identified as: comparing ambient air odour concentration and individual chemicals statistics against impact criteria (maximum impact standard); using fixed and variable separation distances (separation distance standard); maximum emission rate for mixtures of odorants and individual chemical species (maximum emission standard); number of complaints received or annoyance level determined via community surveys (maximum annoyance standard); and requiring use of best available technologies (BAT) to minimize odour emissions (technology standard). The comparison of model-predicted odour concentration statistics against odour impact criteria (OIC) is identified as one of the most common tools used by regulators to evaluate the risk of odour impacts in planning stage assessments and is also used to inform assessment of odour impacts of existing facilities. Special emphasis is given to summarizing OIC (concentration percentile and threshold) and the manner in which they are applied. The way short term odour peak to model time-step mean (peak-to-mean) effects is also captured. Furthermore, the fundamentals of odorant properties, dimensions of nuisance odour, odour sampling and analysis methods and dispersion modelling guidance are provided. Common elements of

* Corresponding author.
E-mail addresses: marlon.b@posgrad.ufsc.br, marlon_brancher@yahoo.com.br (M. Brancher).

http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

mature and effective odour regulation frameworks are identified and an integrated multi-tool strategy is recommended.

Contents

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

1. Introduction

Odour can be defined as a sensation resulting from the interaction of volatile chemical species inhaled through the nose, including sulfur compounds (e.g. sulfides, mercaptans), nitrogen compounds (e.g. ammonia, amines) and volatile organic compounds (e.g. esters, acids, aldehydes, ketones, alcohols) (Leonardos et al., 1969). Environmental odours from anthropogenic origin are usually emitted from industrial and agricultural activities, including waste water treatment plants (WWTP), food industry, rendering plants, landfills, livestock buildings, foundries, petrochemical parks, slaughterhouses, paper and pulp facilities, composting activities. After emission, odorous gases have the potential to interact with receptors generally in a negative fashion. This impact often results in complaints to authorities and, therefore, the regulation of odour pollution is essential to address conflicts. Complaints, in turn, arise from annoyances, adverse effects on human health and price depreciation of properties.

Miscellaneous approaches are used internationally within odour regulatory systems, with methods and tools for management and control supported by ambient air odour concentration and individual chemicals (maximum impact standard); fixed and variable separation distances (separation distance standard); maximum emission rate for odours and individual chemicals (maximum emission standard); number of complaints or annoyance level (maximum annoyance standard); best available technologies – BAT (technology standard). Jurisdictions which did not promulgate regulations with standardized odour methodologies and objective criteria commonly use the principles of Nuisance Law to fundament the management of odour episodes. Therefore, in this work we recognized 5 different approaches used by the jurisdictions to assess odour impacts and consequently to regulate on environmental odours.

One of the impact assessment techniques most commonly applied use odour emission rates, given by the odour concentration multiplied by the volume flow rate of the source, and simulation of topographic and meteorological data of the site to estimate the odour dilution in the surrounding environment by using dispersion modelling. This technique enables prediction of the distance that is likely to be reached by the plume from the emission source and the ambient air odour concentrations at the receptors (i.e. immission limits). Once the odour concentrations statistics are calculated, these are compared against a jurisdictional immission standard, called odour impact criteria (OIC), to define compliance (Needham and Freeman, 2009). In this paper, OIC include limits formed by three components: odour concentration threshold, percentile compliance level and the averaging time used to calculate concentrations by means of atmospheric dispersion models. Within a generalist view, the odour concentration threshold and the percentile compliance level of this concentration (i.e. percentile) are usually the two components of OIC (Sommer-Quabach et al., 2014). Hourly mean concentrations simulated by dispersion models can mask peak odour episodes because the odour sensation of the human nose occurs in seconds. Therefore, short-time peak concentrations, derived from 1-h mean values, can also be incorporated into odour limits (Schauberger et al., 2012a).

Dispersion models typically calculate odour concentrations at each receptor point of interest within the modelling domain. If a percentile compliance level of 99.5 (99.5% of the time) is required – considering an hourly meteorological dataset over a year –, 8760 concentrations in ambient air for each receptor are calculated. This means that the 44 highest 1-h odour concentrations exceeding the specified concentration threshold are allowed. Consequently, the odour impacts of these exceedances must be tolerated in this period (Brancher et al., 2016).

The FIDOL factors or dimensions of nuisance odour provide a commonly accepted basis for the development of jurisdictional criteria of environmental odours (Griffiths, 2014). This acronym stands for frequency (F), intensity (I), duration (D), offensiveness (O), and location (L) (Watts and Sweeten, 1995; Freeman and Cudmore, 2002). When it comes to odours, the technical differences between annoyance and nuisance need to be clarified. Annoyance is the adverse effect occurring from an immediate exposure; and nuisance is the adverse effect caused cumulatively, due to repeated events of annoyance typically over an extended period (Van Harreveld, 2001). These terms, together with disamenity, are sometimes used as synonyms.

The benefits of implementing objective and scientifically supported quantitative air quality standards that adequately protect the population from odour impacts are widely acknowledged. Such criteria, established by regulations, provide to the public an understanding of the degree of protection against odours as society increasingly demands transparent and uniform environmental regulations. Furthermore, numerical guidelines with which success in preventing or mitigating odour episodes could be effectively measured by those responsible for the odour sources. In some instances, calibration of these numerical guidelines might be undertaken by those industry sectors associated with odour generating activities. The industry and livestock sectors necessitate a predictable and clear set of performance criteria, to be able to plan investments in environmental management. Specially, the adoption of objective limits shifts the emphasis from pollution removal to pollution prevention (Van Harreveld, 2003; Nicell, 2009).

The aim of this work is to provide a comprehensive and critical review of the odour policy in 28 selected countries throughout the world. Five main approaches to assess odour impact risk within the odour regulations reviewed were identified. Efforts were placed to summarize the OIC categorized by the maximum impact standard approach. In this regard, the OIC set by the regulations to protect the public from olfactory nuisances were analyzed and compared according to the targeted level of protection. However, the review of each jurisdiction's legislation contemplates more topics, such as the requirement of BAT, consideration of separation distances, use of different odour concentration units and other pertinent aspects. Additionally, an integrated multi-tool strategy that covers all the 5 identified approaches used within current regulatory frameworks is recommended. This integrated strategy can assist the development of odour regulations and make available a solid common basis for setting robust and harmonious regulatory approaches.

2. CICOP dimensions

The CICOP dimensions of odours refer to the characteristics that can be effectively measured by analytical (e.g. physicochemical analyses), sensorial (e.g. dynamic olfactometry) and sense-instrumental methods (e.g. electronic nose) or their combinations

(Gostelow et al., 2001; Capelli et al., 2008). The sensorial perception, in conjunction with analytical measurements, are the most widely used methods for the characterization of odours. When these techniques are combined, odours are described in terms of perceived effects and chemical composition (Gostelow et al., 2001). The five main dimensions classically used to characterize odorous gases are herein designated by the CICOP acronym: concentration (C), intensity (I), character (C), offensiveness (O), and persistency (P).

2.1. Concentration

The odour concentration is the most commonly used dimension to characterize odours for regulatory purposes. Detectability refers to the minimum concentration of odorant required for detection by a specific percentage of the population under investigation (Ruijten et al., 2009). The determination of the odour concentration provides directly comparable data among odour sources. Additionally, the odour concentration is used to calculate odour emission rates and provide input data for atmospheric dispersion models (Bockreis and Steinberg, 2005). The odour concentration is typically determined in a laboratory environment by dynamic dilution olfactometry (Laor et al., 2014) using an apparatus known as olfactometer. The sensors are the noses of human assessors trained to perform such evaluations. As there are no instrumental methods that predict the olfactory responses to a satisfactory level, the human nose is still used as the most suitable sensor (Ruijten et al., 2009). The determination procedure of odour concentration by dynamic olfactometry was standardized in some countries by the following standards: Australia and New Zealand: AS/NZS 4323.3:2001 (AS/NZS, 2001); Europe: EN 13725:2003 (CEN, 2003); U.S.: ASTM E679-04 (ASTM, 2011). Germany adds additional instructions to the application of EN 13725:2003 through VDI 3884 – Part 1:2015 (VDI, 2015b). In the European standard EN 13725:2003 (CEN, 2003), one odour unit (1 ou_E) is associated to a specific concentration of a reference odorant (i.e. n-butanol), which is a certified reference material. European reference odour mass (EROM) is the accepted reference value for the European odour unit, which is equal to a defined mass of n-butanol. This means that one EROM is equivalent to 123 μg n-butanol (CAS-Nr.71-36-3). In other words, 1 EROM evaporated in 1 m^3 of neutral gas gives a concentration of 0.040 μmol mol^{-1} (equal to a volume fraction of 40 ppb_v). Therefore, it is defined that 1 ou_E m^{-3} (European odour unit per cubic meter) corresponds to a concentration of 40 ppb_v or 123 μg of n-butanol (1 EROM) evaporated in 1 m^3 of odorless air at standard conditions (CEN, 2003; Bockreis and Steinberg, 2005; Ruijten et al., 2009). The traceability of odour units for any odorant to that of the reference odorant is based on this linkage. According to CEN (2003), odour concentrations in terms of 'n-butanol mass equivalents' are effectively expressed by this coupling. This relationship is defined only at the odour perception threshold (OPT). The OPT is also called Z_{50} or detection threshold, which differs from the recognition threshold. Under the EN 13725:2003, the standard conditions for olfactometry are established at room temperature (293 K), normal atmospheric pressure (101,3 kPa) on a wet basis – derived from ISO 10780. This applies both to measurement of odour concentration and the volume flow rate of odour emissions. These conditions were chosen by convention to reproduce typical conditions for odour perception.

In odour evaluations, the human sensitivity is the core of the analysis. Therefore, guidelines for selecting panelists are part of the odour standards. The panel should reflect the average odour perception of a population considered "normal". Only panelists with average sensitivity to n-butanol comprised in the range of 20–80 ppb_v and a defined standard deviation are selected for the evaluations (Laor et al., 2014). The European standard for olfactometry is based on the principle of dilution to the OPT. A sample of odorous air can be described in terms of the volume to which it must be diluted for its intensity to be reduced at the level of OPT. This means that the more dilution necessary to make an odour sample undetectable, the higher the odour concentration. The dilution factor necessary to achieve the OPT is known as the odour concentration (Nicell, 2009). The OPT of a complex mixture of odours or single chemical compound is the concentration at which 50% of a panel is able to detect the diluted sample of odorous air under laboratory conditions (CEN, 2003). Accordingly, if the odour concentration was determined to be 210 ou (or 210 ou_E m^{-3}), it implies that the sample should be diluted to 1/210 of the original concentration to be reduced to the level of the OPT. The key elements of EN 13725:2003 are the quality criteria for accuracy and repeatability (Klarenbeek et al., 2014). This standard was subjected to an extensive development and testing period and became the most widely accepted worldwide (Nicell, 2009). The guidelines prescribe sampling and analysis equipment and methodologies to ensure consistent procedures among laboratories, provide comparable inter-laboratory results, and connect the results to a reference material (i.e. n-butanol). Currently, the EN 13725:2003 is under review. The working group responsible for conducting the upgrading process is entitled CEN Technical Committee TC264 Air Quality (Van Harreveld, 2014).

Odorous pollutants can also be measured in terms of their chemical composition (i.e. mass concentration) by physico-chemical methods such as gas chromatography coupled with mass spectrometry (GC–MS). Newer techniques are now available as, for instance, gas chromatography–time of flight-mass spectrometry (GC–TOFMS) for the identification and quantification of compounds at very low concentrations. GC-TOFMS is a fast and highly sensitive method that differs from conventional GC–MS because about 50% more chemicals on the same air sample can be determined (Gutiérrez et al., 2015). Furthermore, direct measurement instruments can be used to evaluate individual chemical compounds (e.g. DRAGER X-am 7000, Jerome 631-X). Nevertheless, odours cannot be properly evaluated using these methods. The usage of chemical sensors for purposes of impact assessment would require the acquisition of highly time resolved, compound specific, qualified low-concentration data which are challenging to accomplish experimentally (Pettarin et al., 2015). However, the nuisance impact of odorous substances also depends on the character or hedonic tone of the constituent compounds, the way that these compounds interact in a mixture, as well as sensitivity and the subjective attitudes of exposed individuals. Due to these limitations, different measurement approaches are necessary to quantify odours when compared to conventional air pollutants (Nicell, 2009).

2.2. Intensity

The intensity is defined as the strength of odour perception or the magnitude of the stimulus that causes the sense of smell. The relationship between the intensity and the logarithm of the odour concentration is linear and can be described as a logarithmic function derived theoretically, in accordance with the Weber-Fechner Law:

$$I = a \log C + b \tag{1}$$

The dependence between intensity and odour concentration can also be represented as a power function, as demonstrated by Steven's Law (Stevens, 1960):

$$I = kC^n \quad (2)$$

A logarithmic transformation applied to this function is graphically represented by a straight line:

$$\log I = n\log C + \log k \quad (3)$$

where, I is the odour intensity; C is the odour concentration; a, b, k and n are constants. Steven's Law and the Weber-Fechner Law are examples of formulas that have wide acceptance to describe intensity–concentration relationships for a particular odorant or complex mixtures (DEP, 2002). These laws may also be used to describe the nuisance-concentration relationship.

Odour intensity is quantified based on reference scales, where the perceived intensity of an odour is compared to the intensity of a standard chemical substance (n-butanol for olfactometry). The main reference scales standards for odour intensity measurement are from Germany: VDI 3882 – Part 1:1992 (VDI, 1992); U.S.: ASTM E544-10 (ASTM, 2010); France: AFNOR X 43-103 (AFNOR, 1993). The principle of German standard VDI 3882 – Part 1:1992 is to present the odour sample to a panel at different degrees of dilution, using a dynamic dilution olfactometer. Assessors are instructed to indicate a value for the perceived intensity in each exposure based on a 7-point scale. The American standard ASTM E544-10 presents two methods: dynamic-scale method and static-scale method. The dynamic-scale method uses a dynamic olfactometer with a continuous flow of n-butanol (standard odorant) for presentation to a panel. The assessors compare the perceived intensity of an odorous air sample to a specific concentration level of the standard odorant arising from the olfactometer. The static-scale method utilizes a set of Erlenmeyer flasks with fixed dilutions of n-butanol in water to generate standard atmospheres of the odorant. The scale of the static method can be constructed by applying a geometric progression of ratio, for example, equal to 2. This type of scaling is based on the recognition that odour intensities are not linearly related to the odour concentration, on the other hand follow a power function (i.e. Steven's Law) (Nicell, 2009). The French standard AFNOR X 43-103 is based on a static method using a 5-point scale constructed from different concentrations of n-butanol in water solution.

The static-scale procedure has been incorporated as a standard practice by odour laboratories because presents low cost configuration and it is easier to be implemented compared to the dynamic-scale method. In addition, field assessments frequently apply the static-scale method to determine odour intensities near odorous sources. For this case, one example is the application of German standard VDI 3940 – Part 3:2010 (VDI, 2010a). When using this standard caution is necessary because the VDI 3940 – Part 3:2010 intensity scale is different from VDI 3882 – Part 1:1992 intensity scale. It's stated that the method presented in VDI 3940 – Part 3:2010 is only applicable to grid or plume measurements.

2.3. Character

The quality of an odour is a nominal scale of measurement range (category), in which the odour is characterized by using a reference vocabulary. Among the numerous odour descriptors available in the literature (Suffet et al., 2004, 2009; Suffet and Rosenfeld, 2007; DEFRA, 2010), we can cite the odour wheel developed by McGinley and McGinley (2002) for description of environmental odour air samples. This wheel presents eight categories admittedly used for the characterization of odours (i.e. vegetable, fruity, floral, medicinal, chemical, fishy, offensive, earthy), with specific descriptors for each category. The result of the odour character can be represented by a radar plot or a histogram. Odour wheels can also be used to support other methods of analyses, such as instrumental techniques (GC-MS), to better outline the nature of odour impact (Hayes et al., 2014).

2.4. Offensiveness

Offensiveness (or hedonic tone) is a measure of the pleasantness and unpleasantness of an odour in a certain concentration/dilution. Additionally, odour offensiveness is related to its character. Assigning a hedonic value to a sample is subjective to each assessor as personal experiences, recent olfactory memories, events in childhood where certain odours are remembered with nostalgia or disgust can be considered during the evaluation. Thus, according to McGinley and McGinley (2002), the offensiveness determined by a panel should not be reflected as expressing the opinion of the general population and the results should be used primarily for comparing the relative pleasantness among odour samples of the same test session, since the evaluations were performed by the same assessors.

A diversity of methods was developed for quantifying the hedonic tone of odours, which typically uses numeric scales as exemplified in Table 1. The offensiveness can be determined by a dynamic-scale method and a static-scale method, as applied for the odour intensity determination. To date, there is no widely recognized and accepted scale to assess the odour offensiveness (Nicell, 2009). The German standard VDI 3882 – Part 2 and the Dutch standard NVN 2818:2005 nl (NEN, 2005) follow a suprathreshold dynamic dilution method to evaluate the hedonic tone of odorous air samples utilizing a 9-point scale. Despite the intrinsic subjectivity involved in the determination of odour offensiveness, by using a standardized approach that includes a preselected panel with principles for participation, as applied in the determination of odour concentration under the EN 13725:2003, the results may be considered representative. Furthermore, different standards can apply to laboratory or field conditions for the determination of hedonic tone. The German standard VDI 3882 – Part 2 is used with a laboratory based olfactometer, while VDI 3940 – Part 3 is used in the field with human assessors. Also noteworthy is that the VDI 3940 – Part 4 (polarity method) is an alternative to VDI 3940 – Part 3.

2.5. Persistency

The persistency describes the rate at which an odour's perceived intensity decreases as the odour is diluted in the atmosphere downwind from the source (McGinley et al., 2000). Hence, the greater the volume of air necessary to dilute an odour below its OPT, the more persistent the odour is. Using Stevens' Law (Equations (2) and (3)), the odorant concentration (dose), expressed as the logarithm of the dilution ratio, and the odour intensity (response), expressed as the logarithm of n-butanol concentration, generates a log-log graph with negative slope. The slope of the line (given by the value of the exponent n) represents the relative persistency. The logarithm of the constant k is related to the intensity of the odour sample at full strength. Therefore, the persistency of an odour can be denoted as a Dose-Response function (McGinley et al., 2000).

3. FIDOL factors

Historically, the factors that comprise the pattern of environmental odour impacts were described in terms of its frequency, intensity, duration and offensiveness, creating, therefore, the FIDO (Watts and Sweeten, 1995). Subsequently, the sensitivity of the

Table 1
Numeric scales of odour offensiveness.

Type	Range	Reference
9 points	From −4 (extremely unpleasant) to +4 (extremely pleasant)	VDI 3882 − Part 2 (VDI, 1994), NVN 2818:2005 nl (NEN, 2005)
10 points	From 1 (tolerable) to 10 (insupportable)	Nicell (1986)
21 points	From −10 (unpleasant) to +10 (pleasant)	McGinley and McGinley (2002)

receiving environment where the odour impacts occur (i.e. location) was added and the well-known FIDOL acronym was established (Freeman and Cudmore, 2002). The FIDOL factors influence the extent to which odours adversely affect communities and this information can be used as a basis for conducting odour impact assessment studies (Freeman and Cudmore, 2002; Nicell, 2009). Odour criteria established in regulations follow, both explicitly and by inference, the FIDOL approach. The frequency is usually related through a percentile (P), which provides the permitted number of exceedances of a specific odour concentration threshold (C_t). The duration refers to the elapsed time during which an odour is perceived. Individuals may be exposed to odours intermittently for short periods or for prolonged and continuous periods. The offensiveness can be designated by the odour character, using a factor to reduce the criterion because of hedonic tone. The location is related to the land use in the surrounding area of an odour source; refers to where a citizen or community (outside the boundaries of the facility) or sensitive receptors (predetermined points of interest, e.g. schools, hospitals, places of complaints) are placed; the location factor can also consider socioeconomic, tolerance and expectation issues (MfE, 2003; DEFRA, 2010; ERM, 2012; Bull et al., 2014). The FIDOL factors are briefly outlined in Table 2.

4. Atmospheric dispersion modelling

The transport and dispersion of pollutants are affected by different scales of atmospheric motion. Scales, in turn, are classified according to their size in microscale, mesoscale, synoptic and planetary scale or macroscale (Godish, 2004). The planetary boundary layer (PBL) is the portion of the troposphere that is directly influenced by the Earth's surface and responds to combined action of mechanical and thermal forcings, in the order of 1-h timescale (Stull, 1988). The troposphere can be divided into PBL, which extends from the Earth's surface to about 1 km, and the free troposphere, extending from about 1 km to the tropopause. The air that moves vertically undergoes temperature changes as a consequence of the local atmospheric pressure. For dry air, the rate of change of the temperature with altitude is around 1 °C per 100 m − also called Dry Adiabatic Lapse Rate (Seinfeld and Pandis, 2006). The transport of a pollutant emitted into the PBL suffers the action of mechanical turbulence (wind speed, presence of obstacles, topography) and/or thermal turbulence (heating and cooling of the Earth's surface). Within the PBL terrestrial life is developed. Additionally, it is the region which contains most of the emission sources of air pollutants (Turner, 1994). Indeed, most of the gases and vapors from anthropogenic activities or natural processes enters the atmosphere through the lower level of the troposphere (i.e. PBL). After emission, the pollutants can be dispersed and diluted quickly, resulting in low concentrations levels; at other times, they can be concentrated in a relatively small volume, which leads to an episode of air pollution. This extent of mixture is largely determined by the temperature profile of the atmosphere and the wind speed (Seinfeld and Pandis, 2006). It is undoubtedly agreed that air quality depends not only on emission sources, but also more decisively, on meteorological parameters with multifaceted characteristics over various spatio-temporal scales (Juneng et al., 2011).

Table 2
Summary description of the FIDOL factors.

Factor	Description
Frequency	How often receptors are exposed to odours
Intensity	Perception of the odour strength or odour concentration
Duration	Elapsed time during a particular odour episode
Offensiveness	The subjective rating of the (un)pleasantness of an odour
Location	Sensitivity of the receptor; related to the land use

One of the core purposes of the study of atmospheric behavior is to mathematically describe the spatial and temporal distribution of pollutants emitted into the atmosphere (Seinfeld and Pandis, 2006). The qualitative aspect of dispersion theory is to describe or predict the fate of atmospheric emissions from a source (e.g. point, area or line). Quantitatively, the dispersion theory provides a means to estimate concentrations of a pollutant in the atmosphere using meteorological parameters, source characteristics and topographical features. The most frequently approaches applied to describe the turbulent diffusion and develop air pollution models are (Zannetti, 1993; Seinfeld and Pandis, 2006; Colls and Tiwary, 2010):

- Lagrangian: variations in concentration are described in relation to the moving fluid;
- Eulerian: the behavior of the species is described in relation to a fixed coordinate system. The Eulerian description is a common form to describe heat and mass transfer phenomena;
- Gaussian: gaussian models are constructed based on the normal probability distribution of fluctuations in the wind vector (and therefore pollutant concentration). Strictly speaking, this approach is a subset of the Eulerian models. However, generally gaussian models are treated separately;
- Semi-empirical: mainly based on empirical parameterization;
- Stochastic: semi-empirical or statistics methods used to analyze periodicities, trends and interrelationships of air quality measurements and to forecast episodes of air pollution;
- Receptor: considers the concentrations observed in a receptor point to estimate contributions of different emission sources.

Among the methods applied for odour impact assessment, the use of mathematical models to predict concentrations in ambient air downwind of the emission source is the most commonly used (Nicell, 2009). Consequently, the majority of odour regulations around the world nowadays are based on the application of the dispersion modelling (Capelli et al., 2013). Dispersion models can consume less time and financial resources than measurement of odours in the field (Ranzato et al., 2012). Many modern dispersion models provide graphical results of concentration and frequency isolines (contour plots). The concentration isolines display the spatial distribution of odour concentrations in accordance with the permitted level of exceedance of this concentration (i.e. percentile) and are useful to demonstrate where the maximum ground level impacts occur. It is also possible to extract tabular results and perform statistical analyses specific by receptor point and to rank the simulated concentrations over all receptor points. These outputs are relevant tools in forming a basis for assessing the extent

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

and degree of odour impacts on a community and for the establishment of compliance with regulatory criteria (Nicell, 2009; EHP, 2013). In general, the most common models used to simulate the dispersion of odorous compounds are those of Gaussian plume (e.g. AERMOD) and Gaussian puffs (e.g. CALPUFF) (Capelli et al., 2013). AERMOD is a Gaussian plume model that considers no meteorological fluctuations within space and the time interval (wind field is homogeneous). Therefore, steady state conditions are adopted for this period (Cimorelli et al., 2004, 2005). CALPUFF is a multi-layer and multi-species non-steady state Gaussian puff dispersion model, which can simulate the effects of time and space-varying meteorological conditions with three dimensional fields on pollutant transport, transformation and removal (Scire et al., 2000). Another model used for odour dispersion is AUSTAL2000. This model is a Lagrangian particle tracking air dispersion model that has implemented its own diagnostic wind field model. AUSTAL2000 takes into account the influence of terrain on the wind field and, consequently, on the dispersion of pollutants. In some jurisdictions the use of a particular dispersion model is not mandated. However, the model selected for assessments needs to be justified on a case-by-case basis.

5. Basic peak-to-mean theory

Because a typical human inhalation occurs on average in 1.6 s (Mainland and Sobel, 2006), odour episodes, characterized by high concentration peaks, frequently are experienced in the short term, exposing individuals living adjacent of odour sources to olfactory nuisances. Dispersion modelling is a recognized methodology for odour impact assessment, where two approaches can be adopted: (i) calculate hourly mean concentrations, which may underestimate odour concentration peaks and thus mask nuisances; (ii) calculate short-term odour concentrations from the 1-h mean values (Drew et al., 2007). Therefore, dispersion models, which generally calculate hourly mean concentrations of pollutants need to be adapted somehow to parameterize the short-term peak odour concentrations. In this sense, the peak-to-mean approach is a solution to parameterize short-term concentrations in dispersion models applied in several European countries as well as USA and Australia (Piringer et al., 2014). Early works on concentration fluctuations in atmospheric dispersion plumes were presented by Frank Gifford (Gifford, 1959, 1960), where the peak-to-mean ratio approach generally expressed the fluctuations (Ramsdell Jr and Hinos, 1971). Subsequently, Högström (1972) reported that, despite the hourly mean odour concentration is lower than the OPT in some circumstances, odour concentration peaks above the OPT may occur during this period, leading to odour episodes. Fig. 1 presents odour concentration values for different averaging times. For the 1-h mean value, the OPT (illustrated as 1 $ou_E\ m^{-3}$) is not exceeded. For the 12-min mean values, one concentration value is superior than the OPT. For short-term concentrations (12 s), values in the range of 5–6 $ou_E\ m^{-3}$ can be expected, which means a distinct odour perception over several breaths. Fig. 1 shows that the shorter the selected time interval, the greater the maximum concentration. For the shorter period, corresponding to 12 s, a new time series pattern is demonstrated. Over the 300 intervals of 12 s included in 1 h, a certain percentage of null observations (i.e. concentrations equal to 0 $ou_E\ m^{-3}$) can be expected. The frequency of intervals different from zero is called intermittency (Schauberger et al., 2012a). Notably, odour episodes may occur at intervals of less than 12 s because the single breath by the human nose takes place in a fraction of seconds, characterizing an instantaneous perception. Therefore, the real odour peak concentrations that are experienced on receptors can be superior than the 12 s mean values reported in Fig. 1. This demonstrates the relevance of the averaging time for the assessment of odour impacts (De Melo Lisboa et al., 2006; Nicell, 2009). The peak-to-mean concept is the most widely adopted method for adapting long-term concentrations calculated using dispersion models into short-term concentrations. It is assumed that the determination of the peak concentration is more appropriate to describe the odour sensation of the human nose than the longer term mean value (De Melo Lisboa et al., 2006; Schauberger et al., 2012a; Sommer-Quabach et al., 2014).

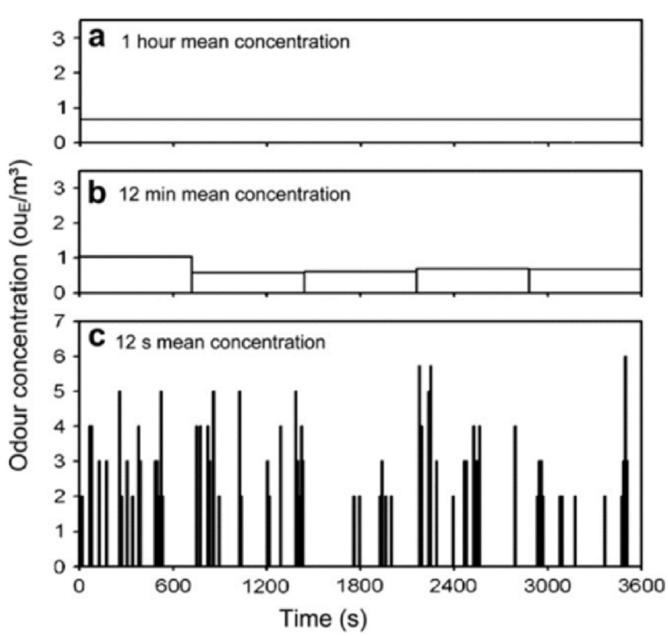


Fig. 1. Timeplot of odour concentrations ($ou_E\ m^{-3}$) for three intervals: (a) hourly mean concentration; (b) 12-min mean concentrations (c) 12-s mean concentration observed at a single receptor during a field inspection. The 12-s mean concentrations values were recorded and then used to calculate the 12-min mean and the hourly mean concentrations. Source: adapted from Nicell (2009) by Schauberger et al. (2012a).

From the long-term mean concentration, short-term concentration can be calculated using the relation described by Smith (1973) (Schauberger et al., 2012a; Piringer et al., 2015):

$$C_p = C_m\, x \left(\frac{tm}{tp}\right)^n \tag{4}$$

where, C_m and C_p are the concentrations for longer and shorter times, respectively (e.g. in odour units); t_m and t_p are the longer times (e.g. hours) and shorter times (e.g. seconds or minutes); and n is an empirical exponent (dimensionless) and ranges from 0.2 to 0.5 (Venkatram, 2002) or from 0.18 to 0.68 (Beychock, 1994). A value of n equals to 0.28 has been commonly used for this purpose, according to Nicell (2009). Other authors (Vieira de Melo et al., 2012) consider $n = 0.2$ as the most used value in the literature. The CALPUFF model manual also recommends the usage of 0.2 (Scire et al., 2000). The Australian regulatory model (AUSPLUME) usually inputs 0.2 for the exponent n (ERM, 2012). The utilization of a constant factor to mimic the human nose is a simplification, since this number depends on the distance from the source, atmospheric turbulence (i.e. stability), intermittency, source configuration. For instance, values for high stacks are typically superior than 0.3, and for non-point sources values around 0.14 were reported (Freeman and Cudmore, 2002; Schauberger et al., 2012a; Sommer-Quabach et al., 2014; Piringer et al., 2015).

According to Equation (4), a peak-to-mean factor is defined by $F = C_p/C_m$. As a result, F can be determined from the relationship (t_m/

$t_p)^n$ that multiplies the concentrations (C_m) simulated by dispersion models to determine peak concentrations (C_p). The shorter the integration time, the higher the peak-to-mean factor F (Sommer-Quabach et al., 2014). For example, the air quality model AUSTAL2000, developed by the German Federal Environmental Agency (UBA), calculates 1-h mean concentrations and multiplying these values by a constant factor of 4 over all types of source, stability conditions and distances, then "odour-hours" are derived. If the ambient odour concentration exceeds the limit of 0.25 ou (odour threshold of 1 ou divided by factor 4) this hour is computed as one odour-hour (TA-Luft, 2002).

6. Odour regulations

6.1. America

6.1.1. Canada

In Canada, odours are not regulated federally. This issue is dedicated to the provinces and territories (state level) or local authorities (municipality). For Alberta, Newfoundland and Labrador, Saskatchewan, Prince Edward Island, British Columbia, New Brunswick, Nova Scotia, Northwest Territories, Yukon, Nunavut no specific odour impact criteria (maximum impact standard) based on times series of ambient air odour concentrations calculated by dispersion models were established to date; the odour is generally regulated by the principles of Nuisance Law. Some Canandian provinces and territories embedded air quality standards in their regulations, including limits for odour-related compounds (e.g. H_2S and NH_3) and fixed separation distances to avoid nuisances. Moreover, it is worth noting the "Guide of good practices related to odour management in Alberta" prepared by Clean Air Strategic Alliance (CASA) in 2015. For the provinces and cities described below, sampling is performed at the emission source and analyzed by dynamic olfactometry commonly using EN 13725:2003 and ASTM E679-04.

6.1.1.1. Quebec. The Minister of Sustainable Development, Environment and Parks (MDDEP) promulgated in 2011 the Clean Air Regulation (chapter Q-2, r. 4.1, O.C. 501-2011) which gives, among other provisions, emission standards and air quality standards for airborne pollutants. Ambient air quality standards are set for a variety of individual hazardous air pollutants, including H_2S, and maximum emission standards applicable to certain industrial/commercial facilities and activities. Under the Environment Quality Act (R.S.Q., chapter Q-2), odour is considered a "contaminant" and in Article 19.1 and Article 20 are found citations that involve odour pollution. However, objective exposure limits are not mentioned in the Environment Quality Act. Guidelines for specific sectors including composting (MDDEP, 2012) and biogas activities (MDDEP, 2011) established odour impact criteria in ambient air, as follows:

- 1 $ou_E\ m^{-3}$ at the 98th percentile and;
- 5 $ou_E\ m^{-3}$at the 99.5th percentile.

To simulate short-term concentrations, an averaging time of 4-min is considered and a peak-to-mean factor F of 1.9 is used to adapt hourly results. Detailed guidance on dispersion modelling is provided in Leduc (2005). These criteria are applied concurrently in the closest residential or commercial area or the first neighbor (receptor). Therefore, a multi-percentile concept is considered. Despite the results of the odour dispersion study, for new composting sites with volume of material less than or equal to 7500 m^3, a minimum separation distance (S_d) of 500 m from any residential, commercial, residential or public places must be respected during the implementation of outdoors facilities. In the case of a domestic composting sites, the S_d may be reduced to 250 m. For a developer that does not conduct a dispersion study, the S_d will be increased to 1 km. In the case of composting sites processing more than 7500 m^3 of material, despite the results of the odour dispersion study, a S_d of 1 km from sensitive land uses must be respected. The S_d can be reduced to 500 m if certain operating practices are followed (MDDEP, 2012). For biogas activities, a S_d of 1 km should be respected when the facility is implanted in residential, commercial, residential or public areas independently of the dispersion modelling results. This S_d can be reduced to 500 m if certain operating practices are followed (MDDEP, 2011).

In the Montreal Urban Community (CUM), *Règlement No. 90* was enacted in 1986 to manage the air quality in the Montreal agglomeration and the status is still in force. Regarding odours, the approach of this By-Law uses sources measurements using olfactometry analysis and compliance is required against the impact criterion set at (CUM, 2001):

- 1 ou not to be exceeded outside of the facility fence line.

Dispersion simulation is conducted using a simplified Gaussian calculation defined in "Equation 3.04".

The city of Boucherville also has a By-Law (*Règlement Numéro* 2008-109) to control odour emission on its territory. This regulation states in Article 4 that (Boucherville, 2008):

- An odour concentration < 10 $ou_E\ m^{-3}$ must be respected always (100th percentile);
- An odour concentration < 5 $ou_E\ m^{-3}$ must be respected in 98% of the time (98th percentile).

A $F = 1.9$ is utilized to calculate 4-min concentrations from hourly values. AERMOD is the regulatory air quality model and guidance for dispersion modelling is provided in Annex 2. All industrial and commercial activities within the territory of the city of Boucherville are covered by this Regulation with exceptions made in Article 3. Odour impacts are calculated 1.5 m above the ground at the fence line or at the limits of industrial areas if the facility is located inside an industrial area. In case of significant deviation or frequently exceeded the criteria set in Article 4, authorities may require the implantation of an electronic nose system to continuously monitor emissions sources to provide real time odour data.

6.1.1.2. Manitoba. Manitoba Conservation has a strategy for managing odour nuisance from developments subject to licensing under its Environment Act (*Loi Sur L'environnement, c. E125 de la C.P.L.M.*). Odour criteria applied are (Manitoba, 2005):

- 2 ou for residential areas;
- 7 ou for industrial zones.

The maximum desirable level is an odour concentration <1 ou. The period that the odour is measured is specified as two tests to be conducted between 15 min and 60 min apart. These limits are used only for evaluating potential impacts on a community for new or modified developments. However, the word "measured" and the interval set for the "tests" suggest field evaluations, which is not possible to perform beforehand for new or expansion of existing facilities. This is only possible with a predictive technique: dispersion modelling. To overcome this, the Draft on Air Dispersion Modelling Protocol for Assessing Odour Impacts in Manitoba is used (Manitoba Conservation, 2006). According to this document, in any odour modelling project at least one of two levels of odour dispersion modelling should be conducted: screening (Screen3) and/or refined (AERMOD, ISC3, ISC-PRIME, CALPUFF). Hourly averages are converted into 3-min averages using Equation (4) by multiplying model outputs for a F which varies from 2 to 7, depending on atmospheric stability. Correspondingly, to convert from 30-min values, model outputs are multiplied by 1.7–4.5, also depending on the atmospheric stability. The exponent n varies from 0.23 to 0.65. This conversion would be simple for screening modelling. However, for refined dispersion modelling, such conversion requires a lot of effort. As a simplification to reduce the complexity for proponents, exponent n can be assumed to be 0.28 over all stability classes. Consequently, 1-h mean concentrations are multiplied by $F = 2.3$ and 30-min concentrations by $F = 1.9$ to produce 3-min results (Manitoba Conservation, 2006).

For screening and refined odour dispersion modelling, the maximum off-site concentrations and the maximum concentrations at the site-specific receptors are required (100th percentile). Preferably, the model should be run using five years of meteorological data to encompass a large amount of atmospheric conditions. A minimum of one complete year of meteorological data is necessary for the refined model, and the year chosen should be representative of the meteorology of the area over the longer term (Manitoba Conservation, 2006).

6.1.1.3. Ontario. Presently in Ontario, odours are regulated by the Environmental Protection Act (R.S.O 1990, C. E.19), in Section 6, where odour is a prohibited contaminant. Besides, Ontario's Ambient Air Quality Criteria (2012), under regulation Ontario Regulation 419/05, sets permitted concentrations for an extensive list of hazardous chemical compounds in ambient air, including odour-related pollutants. Dispersion modelling procedures are also covered by this regulation. The guideline for air dispersion modelling (OMOE, 2009) provides directions on complying with the dispersion model requirements of O. Reg. 419/05. In Section 4.4 (Averaging periods), Equation (4), previously described, is used to convert averages among different periods. The exponent n equals to 0.28 is applied for this purpose. Therefore, to convert from hourly concentration values to 10-min concentrations, for instance, a factor of 1.65 is used. Approved dispersion models are AERMOD and SCREEN3. Alternative models can be utilized under site specific consideration. For odour impact assessment, according to Ferguson and Tebbutt (2015) the Ontario Ministry of the Environment and Climate Change (MOECC) suggest that:

- 1 ou for sensitive land uses should not be exceed in 0.5% of the time (99.5th percentile) over 10-min averaging time.

This limit is not established in a regulation, however is used routinely in permitting approvals and abatement processes when public complaints from odour emissions are common. Furthermore, this criterion may be written as a special condition into air permits, which gives it the force of law. Compliance is demonstrated by quantifying odour emission rates of the sources and simulate off-site impacts using dispersion modelling (Ferguson and Tebbutt, 2015). Ontario also established regulations of minimum separation distances for sewage treatment plants, agricultural and industrial facilities.

6.1.2. Chile

Currently air pollution legislation in Chile, regarding environmental odour exposure, includes emission standards for total reduced sulfur compounds (TRS) associated with the manufacture of sulphated pulp industry. Complaints to the Health Authority are handled with jurisdictional intervention through a protection resource, and subsequent interventions are counted among the actions taken against specific odour episodes. Many landmark complaints related to odour conflicts occurred in Chile in recent years. Particularly, during 2012, a swine production facility, located in the commune of Freirina (Atacama), caused serious socio-environmental issues in the community due to odour episodes. This event, associated with the fact that legal limits or target values for odours or chemical compounds, except for TRS, are not regulated in Chile, mobilized the Ministry of Environment which leaded to development a document called Strategy for Odours Management in Chile (2014–2017) (Ministry of the Environment, 2013). The objective of this report is to enforce the regulatory framework with short, medium and long term measures. This will enable to address the odour management with a comprehensive approach to quantify, control and prevent the formation of the pollutant, in addition to establishing odour criteria. To date, the standards homologated in Chile by the National Institute of Normalization (INN) are: NCh3387:2015: Air Quality – Assessment of odour annoyance – Survey (INN, 2015b), reference to German standard VDI 3883 Part 1:2015 (VDI, 2015a); NCh3386:2015: Air Quality – Static sampling for olfactometry (INN, 2015a), reference to German standard VDI 3880:2011 (VDI, 2011); NCh3190:2010: Air Quality – Determination of odour concentration by dynamic olfactometry (INN, 2010), reference to European standard EN 13725:2003 (CEN, 2003).

6.1.3. Colombia

The Resolution 1541:2013 (MINAMBIENTE, 2013) establishes directives in Colombia for dealing out with complaints, ambient air quality standards and source emission assessment of offensive odours. The application of this resolution is accomplished in this fashion: (i) presentation of the complaint as an indicator of the existence of an alleged odour issue; (ii) evaluation of the complaint using standardized surveys; (iii) requirement of the plan to reduce the impact of offensive odours (PRIO) by the authority to the odour-emitting activity; (iv) plan implementation, assessment and monitoring by the authority; (v) measurement in case of noncompliance of the PRIO. The authority will have thirty (30) working days to evaluate the odour complaint, after the presentation of the alleged nuisance. Within this period, a visit to the activity can be conducted. Upon expiration of the period, the authority will have thirty (30) calendar days to issue the administrative act. Then, the feasibility to require to the facility the presentation of a PRIO will be decided. The activity must present a PRIO within the next three (3) months to the regulator, in accordance with Chapter V of the Resolution 1541:2013 (MINAMBIENTE, 2013). To evaluate complaints, Resolution 2087:2014 (MINAMBIENTE, 2014) must be followed using the Colombian Technical Standard NTC 6012-1:2013 (ICONTEC, 2013).

Basically, the PRIO must contain the following information: location and description of the activity; description, design and technical justification for the effectiveness of good practice or BAT to be implemented in the generating process of the offensive odours; specific goals; contingency plan; chronogram of implementation. As impact indicator of the PRIO, the number of hours in which offensive odours are perceived is performed using the Colombian Technical Standards NTC 6049-1:2014 (ICONTEC, 2014a) and 6049-2:2014 (ICONTEC, 2014b).

The OIC applied in Colombia for mixtures of chemicals (i.e. odours) according to Resolution 1541:2013 are set by offensiveness, as follows:

- 3 $ou_E\ m^{-3}$ for processing and preservation of meat, fish, crustaceans and mollusks, production of oil refining products, manufacture of cellulose pulp, paper and cardboard, tanning and leather retanning; retanning and dyeing of fur, treatment and disposal of non-hazardous waste and transfer plants, wastewater treatment plants, water catchment in water bodies

receiving dumps, manufacture of chemicals and basic chemicals products, heat treatment of animal by-products;
- 5 ou_E m^{-3} for livestock production unit; preparation of vegetable oils and greases;
- 7 ou_E m^{-3} for decaffeination, toast and coffee grinding and other activities.

The 98th percentile of modelled 1-h concentrations on an annual basis is extracted for compliance. Therefore, OIC in Colombia are regulated considering the FIDO factors: frequency, intensity (or concentration), duration and offensiveness. The location is the only factor that is not taken into account. As compliance with the 98th percentile is required, in approximately 175 h (~7.3 days) during a typical year the impact should be accepted at each receptor point in the modelling domain. Furthermore, the more offensive the odour is, lower the tolerable level of odour concentration. Dispersion modelling covered by Resolution 1541:2013 should be performed according to the guide adopted by the Ministry of Environment, Housing and Territorial Development. While the Guide to Air Quality Modelling is issued, the simulations should be carried out using atmospheric dispersion models recommended by the Environmental Protection Agency of the United States (USEPA): CALPUFF and AERMOD. As there is no mention to address short-term odour peaks, it can be assumed that $F = 1$ and odour concentrations calculated using dispersion models are on hourly basis. The method used to measure odours is detailed in the Colombian standard NTC 5880:2011 (ICONTEC, 2011), adopted identically from the European standard EN 13725:2003. Moreover, individual chemical compounds that may cause odour episodes are addressed by Resolution 1541:2013 ambient air quality standards. The levels are set at reference conditions (i.e. 25 °C and 1013 hPa) and apply to the activities described previously. Regulated chemicals are H_2S, TRS and NH_3 with daily limits of 7, 7 and 91 μg m^{-3}. The hourly limits for H_2S, TRS and NH_3 are 30, 40 and 1400 μg m^{-3}, respectively.

6.1.4. United States of America

The U. S. Environmental Protection Agency (USEPA), under the Clean Air Act, does not regulate odours as an airborne pollutant. Therefore, odour pollution is not addressed within the National Ambient Air Quality Standards (NAAQS) or any other federal regulatory framework. According to Epstein and Freeman (2004), odour regulations in 42 of the 50 states in the USA are addressed by the principles of Nuisance Laws. These regulations make mention of either "nuisance" or "quality of life" terminologies. Moreover, some states provide odour regulations with the common approach of fixing ambient odour dilution-to-threshold (D/T) limits. The D/T values are measured using a field olfactometer. And, the typical field olfactometers used for this purpose in U.S. are the Scentometer and Nasal Ranger (McGinley and McGinley, 2014). Recently, the Scentroid SM100 was also put available in the market. More information on field olfactometers can be found in the work of Walgraeve et al. (2015).

Ten states regulate odours using the principle of D/T: Colorado (Regulation No. 2), Connecticut (Regulation 22a-174-23), Delaware (Air Regulation Number 1119), Illinois (Title 35, Subtitle B, Chapter 1, Part 245), Kentucky (Regulation 401KAR53:010), Missouri (Title 10, Chapter 6, Section 165), Nevada (NAC 445B.22087), North Dakota (Chapter 33-15-16), West Virginia (Title 45, Series 4), Wyoming (Chapter 2, Section 11). Other states vaguely mention odours with the use of field olfactometry or D/T method: Massachusetts, North Carolina, Oregon Pennsylvania, Washington (McGinley and McGinley, 2014). Local governments can also stipulate odour regulations (e.g. city of Oakland, city of San Diego, city of Seattle, Allegheny County).

For instance, the Colorado Air Quality Control Commission by means of Regulation No. 2 (Odor Emission, 5 CCR 1001-4), indicates that for all types of sources (except manufacturing process), the maximum allowable odour concentration is 7 D/T for areas used predominantly for residential or commercial purposes and 15 D/T for all other land uses. Furthermore, for housed commercial swine feeding operations and agricultural production other limits are set because they are not considered a major stationary source. In this case, the maximum acceptable odour concentration at or beyond property boundary is 7 D/T and at any off-site receptor is 2 D/T. This regulation stipulates that two odour measurements shall be made within a period of 1 h with these measurements being separated by at least 15 min. Personnel for evaluating odours are selected using a "detectability rating test" as outline in "Selection and Training of Judges for Sensory Evaluation of the Intensity and Character of Diesel Exhaust Odors". In the Bay Area Air Quality Management District (BAAQMD), in San Francisco, the limit is 5 D/T at or beyond the facility fence line applied after at least 10 complaints within a 90-day period (Regulation 7-302).

Therefore, field olfactometry is the most employed technique to assess odour pollution levels within the U.S. jurisdictions. The application of the field olfactometry under the U.S. regulations is practical to implement and does not require much time and financial resources when compared to more robust methodologies such as dispersion modelling and long-term field survey assessments. However, it can lead to inconsistencies if applied randomly. In situ, measurements are subject to have a fundamental methodological weakness: the sensory observations are momentary and governed by meteorological conditions and emission profile of the odour source at the moment. Sites with meteorological effects changing frequently and installations with discontinuous emission can lead to results that are instantaneous pictures. Accordingly, a well-defined standardized procedure is essential to secure reliable results. The frequency and the duration of odours (part of the FIDOL), which are noteworthy dimensions of nuisance odour, are not solidly taken into consideration. Although values of D/T are theoretically comparable to UO_E m^{-3}, this type of criterion are not based on time series of odour concentration calculated by dispersion models. For this reason, U.S. odour regulations are not summarized in Table 3.

Separation distances are also used in some jurisdictions (e.g. Illinois, Iowa, Kansas, Missouri, North Carolina, Oklahoma, South Carolina, South Dakota, Wyoming) for livestock activities. In addition, ambient air concentration limits for odour-related chemical compounds are set as well (e.g. California, Connecticut, Idaho, Minnesota, Nebraska, New Mexico, New York State, New York City, North Dakota, Pennsylvania) (Mahin, 2001). Odorous air samples are measured using the American standard ASTM E679-04. If an odour laboratory operates in accordance with EN 13725:2003 triangular forced-choice method, the requirements of ASTM E679-04 are fulfilled (McGinley and McGinley, 2014).

6.1.5. Panama

The Republic of Panama, through the National Environmental Authority (ANAM), produced the Draft Standard for Control of Nuisance Odours (URS Holdings, 2006). In the Draft, field olfactometer is defined as a tool for preliminary odour assessments. Article 28 defines the application of field olfactometry. To verify compliance, the results of the measurements of odour intensity (or concentration) of the potential odour-emitting facility will be analyzed relying on the type of source (point or area) and the location (land use). For area sources, measurements at the fence boundary of the installation must attend the following limits:

- Residential or commercial: 15 D/T;
- Industrial or rural: 30 D/T.

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

Table 3
International regulatory framework on odour impact criteria (maximum impact standard) based on time series of ambient air odour concentration calculated by dispersion models. C_t: odour concentration threshold; P: percentile (compliance frequency); A_t: averaging time; *F*: peak-to-mean factor. When *F* is equal to one (1), short-term concentrations are not considered, no recommendations for calculating short-term values were established in the regulations or *F* is embedded in the hourly mean value.

Jurisdiction	Odour impact criteria		A_t	*F*	Protection level		Reference
	C_t (odour units)	P (%)					
Australia							
Queensland	0.5	99.5	1 h	1	Wake-free stacks		EHP (2013)
	2.5				Ground-level sources and wake-affected stacks		
	1.0				Meat chicken farms	Boundary of a non-rural zone	DAFF (2012)
	2.5					Sensitive land use rural zone	
New South Wales	2	99	1 s	[a]	pop. ≥ 2000	At the nearest existing or likely future offsite	DEC (2006b)
	3				pop. ~500	sensitive receptor based on population	
	4				pop. ~125	density	
	5				pop.~30		
	6				pop. ~10		
	7				pop. ≤ 2		
South Australia	2	99.9	3 min	[b]	pop. ≥ 2000	At the nearest existing or likely future offsite	SAEPA (2007a)
	4				pop. ~350	sensitive receptor based on population	
	6				pop. ~60	density	
	8				pop. ~12		
	10				pop. <12		
Victoria	1	99.9	3 min	[b]	At or beyond the fence line		EPA Victoria (2001)
	5				Animal husbandry (at or beyond the fence line)		
Western Australia	2 and 4	99.5 and 99.9	3 min	[b]	Sensitive receptors		DEP (2002)
Tasmania	2	99.5	1 h	1	At or beyond the fence line		EPA Tasmania (2004)
New Zealand	1	99.5 [c]	1 h	1	High sensitivity (unstable to semi unstable)		MfE (2003)
	2				High sensitivity (neutral to stable)		
	5				Moderate sensitivity (all conditions)		
	5–10				Low sensitivity (all conditions)		
Austria	1	97	1-5 s	[d]	Spa areas		OAW (1994)
	1 and 5–8	92 and 97			Residential areas		
Hungary	3–5	[e]	[e]	[e]	Separation distances nearby odour sources		Cseh et al. (2010)
Denmark	5–10	99 [f]	1 min	7.8	Industries	Sensitive receptors	DEPA (2002a)
	5	99 [f]	1 h	1	Livestock farms	Urban and recreational zones	DEPA (2009)
	7					Conglomeration in a rural zone	
	15					Individual properties	
Norway	1	99 [f]	1 h	1	Residential areas: at the nearest neighbor		KLIF (2013)
	2				Industrial areas: at the nearest neighbor		
Israel	1, 5, 10	98 99.5 100	10 min	[h]	C_t and P are set based on the land use type and new or existing facilities		IMEP (2013)
Hong Kong	5	100	5 s	[h]	Nearest sensitive receptors		EPD (2016)
Italy							
Lombardy	1 3 5	98	[g]	2.3	Sensitive receptors: new and existing facilities		Regione Lombardia (2012)
Puglia	1, 2, 3, …	98 99.9 100	[g]	2.3	WWTP: sensitive receptors, type of land use, new and existing facilities		Arpa Puglia (2014)
France	5	98	1 h	1	Composting facilities	Sensitive receptors	JORF (2008)
	5	98			Rendering	Existing facilities	JORF (2003)
	5	99.5				New facilities	
Ireland	1.5	98	1 h	1	All situations	Target value	EPA Ireland (2001)
	3				New pig production units	Limit value	
	6				Existing pig production units	Limit value	
Netherlands	0.5	98	1 h	1	WWTP built after 1996	Residential areas	VROM (2007)
	1.0					Industrial areas	
	1.5				WWTP built before 1996	Residential areas	
	3.5					Industrial areas	
	3 (0.1–14)	98	1 h	1	Livestock	Within a concentration area, within the built-up area	VROM (2006b)
	14 (3–35)					Within a concentration area, outside the built-up area	
	2 (0.1–8)					Outside a concentration area, within the built-up area	VROM (2007)
	8 (2–20)					Outside a concentration area, outside the built-up area	
	2.5	98	1 h	1	Forage dryers		InfoMil (2014)
	0.7				Livestock feed industry: new facilities		
	1.4				Livestock feed industry: existing facilities		
	5				Bakeries and pastry		
	1.5				Slaughterhouses		
	2.5				Meat processing		

(*continued on next page*)

Table 3 (*continued*)

Jurisdiction	Odour impact criteria		A_t	*F*	Protection level			Reference
	C_t (odour units)	P (%)						
	>2.5, >5 or ≤ 2.5				Cocoa beans processing industry			
	3.5				Coffee roasters			
	1.5				Breweries			
	1.5				Composting of organic waste: new facilities			
	3.0				Composting of organic waste: existing facilities			
	1 and 5	98 and 99.99	1 h	1	Asphalt mixing plants	New facilities		
	2 and 10	98 and 99.99				Existing facilities		
	5 and 25	98 and 99.99				For situations where the above values are not reasonably feasible or receptors are located in an area of less protection		
	1.5	98			Composting of green waste			
	3	99.5						
	6	99.9						
Flevoland Gelderland Groningen North Brabant Overijsse Zealand South Holland	0.05–100	95–99.99	1 h	1	Industrial facilities	New and existing facilities, sensitive receptors. The C_t is associated with a hedonic tone value		InfoMil (2016a)
UK	1.5	98	1 h	1	Most offensive			EA (2011)
	3				Moderately offensive			
	6				Less offensive			
Spain								
Catalonia	3	98	1 h	1	Most offensive			DMAV (2005)
	5				Moderately offensive			
	7				Less offensive			
Colombia	3	98	1 h	1	Most offensive			MINAMBIENTE (2013)
	5				Moderately offensive			
	7				Less offensive			
Panama	3	[e]	[e]	[e]	Most offensive			URS Holdings (2006)
	6				Moderately offensive			
	10				Less offensive			
Germany	1	98	1 s	4	Irrelevance criterion			TA-Luft (2002)
		90			Residential and mixed areas			GOAA (2008)
		85			Commercial, industrial, agricultural areas			
Belgium								
Walloon	3	98	1 h	1	Composting facilities: nearest dwellings			Gouvernement wallon (2009)
	6				Piggeries facilities: nearest receptors			Nicolas et al. (2008)
	10				Poultry facilities: nearest receptors			
Flanders	0.5	98	1 h	1	Industries: target	high sensitivity	Very unpleasant odours	LNE (2008)
	2					moderate sensitivity		VITO (2012)
	3					low sensitivity		
	2				Industries: limit	high sensitivity		
	5					moderate sensitivity		
	10					low sensitivity		
	1.5				Industries: target	high sensitivity	More pleasant odours	
	3					moderate sensitivity		
	5					low sensitivity		
	3				Industries: limit	high sensitivity		
	5					moderate sensitivity		
	10					low sensitivity		
	0.5				Single livestock farm	Target	New facilities	
	1					Limit		
	1.5					Limit	Existing facilities	
	3				Clusters of livestock farms	Target	All land uses	LNE (2008)
	3					Limit	Highly sensitive receptors	Willems et al. (2015)
	5					Limit	Resid. w/rural character	
	10					Limit	Rural areas	
Canada								
Quebec	1 and 5	98 and 99.5	4 min	1.9	Composting and biogas activities: first sensitive receptors			MDDEP (2011) MDDEP (2012)
City of Boucherville	10 and 5	100 and 98	4 min	1.9	All facilities: first sensitive receptors			Boucherville (2008)
Manitoba	2	100	3 min	2.3	Residential areas			Manitoba Conservation (2006)
	7				Industrial areas			
Ontario	1	99.5	10 min	1.65	Existing facilities: sensitive receptors			Ferguson and Tebbutt (2015)

[a] Fixed peak-to-mean factor (*F*) are dependent upon the type of source, atmospheric stability and distance downwind.

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

[b] No guidelines are provided to determine *F* for an integration time that deviates from 1-h mean value.
[c] The baseline P is 99.5th, although 99.9th is also used to assist in the evaluation of model results depending on the type of source and consistency of emission data (MfE, 2003).
[d] Variable: *F* dynamically depends on the distance from the source and the atmospheric stability (Schauberger et al., 2000, 2013; Piringer et al., 2007, 2014, 2015). In certain circumstances, a constant factor ($F = 4$) used in Germany is adopted.
[e] No guidelines are provided to P, A_t and *F*.
[f] The maximum monthly 99th percentile should be extracted to verify compliance against the criterion.
[g] There is no mention to the short-term A_t derived from hourly values by using a $F = 2.3$.
[h] *F* depends on the Pasquill-Gifford atmospheric stability classes. See Section 6.4.4 and 6.5.3.

For point sources, odour-emitting facilities must comply both limits set at the fence boundary of the facility, as well as the limit at the receptor:

- Residential or commercial: 15 D/T at the fence line and 7 D/T at the receptor;
- Industrial or rural: 30 D/T at the fence line and 15 D/T at the receptor.

This assessment will determine whether the intensity of odours is registered as objectionable odour that requires taking further actions. The measurement times at each point should not be less than 5 min, after verifying and calibration of the equipment. This measurement should be performed in periods of increased activity and checked if they match the hours reported by the complainant. If any of the results obtained during the field evaluation exceeds the limit value set in this standard, the facility will be considered a source of offensive odours (URS Holdings, 2006). If there is no agreement between the authority and the source of offensive odours for the assessment using field olfactometer, in the Article 31 is defined the use of dynamic dilution olfactometry (UNE-EN 13725/2004). In this case, compliance is verified against limits in odour units. The proposed limits were set in terms of offensiveness:

- High offensiveness: 3 ou_E m^{-3};
- Medium offensiveness: 6 ou_E m^{-3};
- Low offensiveness: 10 ou_E m^{-3}.

Criteria must be met outside the boundaries of the facility and there is no mention to averaging time and percentile. The classification of the activities according to the offensiveness is described in Table 5 of Chapter X of the Draft. For instance, most offensive are odour emissions from rendering plants, tanneries, slaughterhouses, refineries; moderately offensive from wastewater treatment plants, landfills, composting facilities, coffee processing, chemical, agrochemical and petrochemical industries, food processing operations and breweries; less offensive from gas stations (URS Holdings, 2006). The Draft also stablished maximum permissible values, at the fence line, for the concentration of chemicals in air that cause odour episodes and maximum values of H_2S and NH_3 for outlet stack emissions. The last version of this document is dated from 2006 (URS Holdings, 2006) and has not undergone further revisions or implemented as an official odour regulation in Panama to this day.

6.1.6. *Brazil*

The Brazilian National Environmental Policy, through the federal Law No. 6938:1981 (Brasil, 1981), launched the concept of environment, environmental quality degradation and pollution. Article 3 defines pollution as the environmental quality degradation resulting from activities that directly or indirectly harm the health, safety and well-being of the population; create adverse conditions for social and economic activities; adversely affect the biota; affect the aesthetic or sanitary conditions of the environment; release materials or energy in disagreement with established environmental standards. Consequently, odour can be interpreted as a form of pollution for the provisions of the Law. Other legal documents address the issue of pollution similarly, as, for instance, Decree No. 76389:1975, which presents concepts about the prevention and control of industrial pollution (Brasil, 1975) and Article 225, from the Constitution of the Federative Republic of Brazil. Article 225 states that “every citizen has the right to an ecologically balanced environment, common use of the people and essential healthy quality of life, imposing to the government and society the duty to defend it and preserve it for present and future generations'. Based in this Article, the Public Ministry from Brazil already considered that odour pollution is a counteraction to a healthy quality of life and, therefore, actions to control odour-emitting sources were imposed mandatorily. Resolution CONAMA 436:2011 (Complements Resolutions No. 05:1989 and No. 382:2006) provides emission limits for air pollutants. The values are set by pollutant and industrial activity. The annoyance caused by odours beyond the boundaries of the site is only mentioned to cellulose manufacturing activities. Resolution 436:2011 delegates to the licensing environmental agency the power to set more stringent emission limits depending on local features of the area where the pollution source is located (CONAMA, 2011). Resolution No. 003:1990 of the National Environment Council (CONAMA, 1990) deals with air quality standards where maximum concentrations in ambient air for conventional atmospheric pollutants are set. However, odour limits are not incorporated. Article 7 remarks that other air quality standards, in addition to the pollutants considered in this Resolution, may be established by CONAMA, if necessary (Brancher et al., 2016).

In Brazil, the states have the autonomy to develop their own regulatory framework regarding air quality. Municipal laws can also be established; however, no city has a solid and objective odour regulation. The legislation of the states described below is used herein to exemplify the current Brazilian situation on odours.

6.1.6.1. *Paraná*

In the state of Paraná, the Resolution SEMA 016:2014, developed by the Secretariat of the Environment and Water Resources, can be considered the reference-odour regulation in Brazil. This Resolution refers, in Article 12, that odour-generating facilities must be implemented to a distance considered sufficient to avoid olfactory nuisances in population centers (Paraná, 2014). Resolution SEMA 016:2014 was issued from the experience acquired in Resolution SEMA 054:2006, in which a maximum odour emission rate of 5×10^6 ou h^{-1} was set for odour-emitting activities or a minimum efficiency of 85%, determined by olfactometry, for abatement systems. Consequently, Resolution SEMA 016:2014, currently in force, regulates the impact on receptors (i.e., immission protection) and no longer fix emissions at source. Nonetheless, criteria to provide an effective and concrete basis to conduct odour impact studies using dispersion models or field evaluations are not established (Brancher et al., 2016).

6.1.6.2. *São Paulo*

The Decree No. 59113:2013 (São Paulo, 2013), from state of São Paulo, sets air quality standards and gives related provisions for conventional airborne pollutants. However, odour pollution is not addressed. The Decree No. 8468:1976 (amended by Decree No. 54.487:2009), which deals with the prevention and control of environmental pollution, provides in Article 33 the prohibition of the emission of odoriferous substances in the atmosphere in amounts that may be perceptible outside the fence line of the facility. The verification of the perception that this article refers will be performed by qualified technicians in the field (São Paulo, 1976). Nonetheless, no other guidance is established for the definition of any method to conduct this confirmation (Brancher et al., 2016). Article 38 sets that odoriferous substances resulting from the following sources should be incinerated by afterburners or using other pollution control system, of equal or greater abatement efficiency: roasting and cooling of coffee, peanuts, cashew nuts and barley; autoclaves and digesters used for rendering; drying ovens or cure for painted, varnished or lithographed parts; asphalt oxidation; smoking meats or similar; sources of hydrogen sulfide and mercaptans; rubber regeneration.

The Environmental Agency of São Paulo State, CETESB, published a manual for licensing process for environmental impact assessment studies (CETESB, 2014). In this document, odours are referenced to the previous Article 33. Moreover, dispersion modelling recommendations are provided in Annex I. Regulatory dispersion models to be used are ISCST3 and AERMOD. However, these recommendations fit to conventional pollutants. No specific guidance for odour dispersion is provided in this manual.

6.1.6.3. Santa Catarina. The state of Santa Catarina, through the Law No. 14675:2009 – Article 290, assigned to the Environment State Council (CONSEMA) the goal to regulate odour criteria and methodologies in a period of one year from the date of publication of this Law. Article 179 states that the definition of air quality standards should be provided in federal regulations, with responsibility given to CONSEMA to establish additional standards by those existing at the federal level (Santa Catarina, 2009). However, to date, methods and criteria related to environmental odours were not regulated for the state of Santa Catarina.

Consequently, up to the present time, specific regulatory instruments, at the federal or state basis, that fix criteria to define legal limits or target values of odour impacts are not set in Brazil. In addition, no specific national standards for sampling and analysis of odours, guidance or technical standards to conduct field impact studies and atmospheric dispersion modelling of odours are existent (Brancher et al., 2016).

6.2. Europe

6.2.1. United Kingdom

The legislative framework in the United Kingdom (UK),[1] under which odours are currently controlled, are the following:

- Environmental Protection Act (EPA);
- Town & Country Planning Act (TCPA);
- Environmental Permitting regulations (EP) (England & Wales);
- Pollution Prevention and Control regulations and Waste Management Licensing regulations (PPC & WML) (Scotland and Northern Ireland).

The EPA applies to all business and trade premises, including industry, agriculture, waste management and wastewater treatment assets. However, in the case of activities are also regulated by conditions imposed upon a planning permission or in law under the EP (or PPC & WML regulations in Scotland and Northern Ireland), frequently there will be a legal and procedural debate as to which piece of legislation should prevail (CIWEM, 2012). In UK, "benchmark" odour criteria provided in the Integrated Pollution Prevention and Control directive (IPPC) are set in Appendix 3 (modelling odour exposure) of the H4 Odour Management (EA, 2011), as follows:

- 1.5 ou_E m^{-3} for odour emission sources as processes involving decaying animal or fish remains, processes involving septic effluent or sludge, biological landfill;
- 3 ou_E m^{-3} for intensive livestock rearing, fat frying (food processing), sugar beet processing, well aerated green waste composting;
- 6 ou_E m^{-3} for brewery, confectionery, coffee.

Accordingly, the limits are designated by offensiveness in three different levels (most offensive, moderately offensive and less offensive). The 98th percentile is applied to the hourly mean concentrations over a year ($F = 1$). Local factors may influence the values of the benchmark limits. If the local population, for instance, has already become sensitized, the C_t may be reduced by 0.5 ou_E m^{-3} (EA, 2011). Although, scientific support for this recommendation is not provided.

The use of the BAT is prerequisite as control measures. Within the European IPPC legislation (Directive 2008/1/EC) and Industrial Emissions Directive (IED 2010/75/EU), the BAT Reference Documents, the so-called BREFs, define the BAT to reduce overall environmental impacts for a variety of sectors. To clarify, these documents are not only applied in UK, but also across others members of European Community. Approved regulatory dispersion models applied for calculation of odour concentration in ambient air are Steady state Gaussian models (e.g. AERMOD, ADMS) and non-steady state Lagrangian models (e.g. CALPUFF and AUSTAL2000). To demonstrate the efficacy of the proposed BAT measures and to test uncertainties, dispersion models are run for different design and "what if" scenarios. Hourly meteorological data for a period of at least three, preferably five years, is required (EA, 2011). Other criteria exist for a diversity of odour assessment methodologies. Nevertheless, as previously stated, this work focuses on quantitative numerical standards for ambient air odour concentration calculated using dispersion modelling. Then, guidance – not described here – from other UK reports also provides technical background information on basic theory of odours, measurement methods, odour management and control, planning purposes (EA, 2002; DEFRA, 2009, 2010; EA, 2010; SEPA, 2010; NIEA, 2012; Bull et al., 2014). Determination of odour concentration by dynamic olfactometry is performed using BS EN 13725:2003. The history of the beginning of the development of odour criteria in UK during the early 90s can be found in Bull et al. (2014).

6.2.2. Germany

German regulatory framework on air quality are based on provisions adopted by the European Union (EU) and, consequently, transposed into German law. This provides harmonisation between EU and Germany's air quality legislation. Additionally, provisions on air quality control at state level are also existent. The Act on the Prevention of Harmful Effects on the Environment Caused by Air Pollution, Noise, Vibration and Similar Phenomena, short Federal Immission Control Act (BImSchG - *Bundes Immissionsschutz Gesetz*) and its administrative regulations and implementing ordinances mainly drive the air quality control in Germany. All kinds of odours from any commercial facility are considered an annoyance,

[1] At the time of preparation of this paper the UK is in the process of leaving the European Union. Even though, the UK air quality regulations are still described herein as part of the European Union.

according to BimSchG. The Technical Instructions on Air Quality Control (TA-Luft, 2002) are an instrument for authorities to manage air pollution. TA-Luft has the aim to protect the general public and the neighborhood against harmful effects of air pollution on the environment and to provide precautions against harmful effects of air pollution to attain a high level of protection for the environment altogether. It contains, among other provisions, directives for the precaution against environmental detriments caused by odour. However, TA-Luft does not bring objective criteria for protection against odour episodes. This is observed within a specific national regulation called Guideline on Odour in Ambient Air (GOAA, 2008).

GOAA deals with odours necessarily arising from industrial and livestock facilities. Odorous gases from road traffic, domestic heating, vegetation, manure spreading, and similar sources are not included. The criteria defined in this guideline are based on the detection of recognizable odour and the odour-hour concept. Odours in ambient air may be recorded only if they can be identified during measurement in the field or in odour exposure prognoses by means of dispersion models. The concept of odour-hour is applied in the guideline VDI 3940 – Part 1:2006 (VDI, 2006) where, "one odour-hour means one positively assessed single measurement. A single measurement has a positive result if the fraction of time during which an odour was unambiguously identified comes up to or exceeds a predefined percentage value. This definition was derived from the general properties of the sense of smell, in particular its pronounced ability to adapt to stimuli. It is assumed that, although the summarized duration of all odour episodes is identical, many short excesses of the odour threshold in one measurement interval have a higher effect on odour annoyance than only a few continuous stimuli with a shortened effect due to adaptation. Consequently, the concept of odour-hours weights many short odour episodes more heavily than fewer long ones" (GOAA, 2008).

The assessment criteria are determined by exposure limit values in ambient air. As a rule, the odour exposure is classified as a severe nuisance if the total odour exposure (EXP_{tot}) exceeds the regulatory exposure limit value (EXP_{lim}) set, as follows:

- Residential and mixed areas: 0.25 ou_E m^{-3} at the 90^{th} percentile;
- Commercial, industrial, agricultural areas: 0.25 ou_E m^{-3} at the 85^{th} percentile.

These limit values, classified by the type of land use, are relative frequencies of odour-hours. A constant *F* of 4 is applied to address hourly mean values from short-time peak concentrations of 1 s. A concentration threshold of 1 ou_E m^{-3} is used, therefore, applying *F*, a $C_t = 0.25$ ou_E m^{-3} for 1-h mean concentration is given. The EXP_{tot} is calculated, in this manner:

$$EXP_{tot} = EXP_{exist} + EXP_{add} \quad (5)$$

where, EXP_{exist} is the characteristic value of the existing odour exposure, and EXP_{add} is the expected additional odour exposure. The existing exposure is the odour exposure originating from the existing installation without the expected additional exposure caused by the development to be licensed. The characteristic value EXP_{exist} is computed for every assessment square of the area under investigation from the results of the grid measurements or dispersion calculation.

The exposure limit of the agricultural land use is applicable only to odours arising from livestock farming considering a nuisance-relevant characteristic value. Therefore, a nuisance-relevant characteristic value $EXP_{tot,nr}$ has to be calculated for the assessment of livestock farming-related odour. The $EXP_{tot,nr}$ value is then compared with the exposure limits to verify compliance. The value of $EXP_{tot,nr}$ results from the multiplication of the EXP_{tot} with the factor f_{tot}:

$$EXP_{tot,nr} = EXP_{tot} \times f_{tot} \quad (6)$$

The factor f_{tot} is calculated in accordance with Section 4.6 of GOAA. In the determination of f_{tot}, weighting factors (f) for individual types of animals, related to the offensiveness, are included. For poultry $f = 1.5$, for fattening pigs $f = 0.75$ and for dairy cows and young cattle the factor is $f = 0.5$. The typical odour frequency of animals not listed will appear without weighting factor in the calculation of f_{tot}. For different odours, the method of polarity profiles according to VDI 3940 – Part 4:2010 (VDI, 2010b) is included into the guideline for hedonic classification. If the hedonic tone of an emission is definitely pleasant, its contribution to the total odour exposure may be weighted by a factor of 0.5. Consequently, the benchmark exposure limit is reduced for unpleasant odours and increased for pleasant odours.

Environmental compliance is attained without further actions to a facility under examination if the total odour exposure (characteristic value of the expected additional odour exposure) using the 98^{th} percentile does not exceed 0.25 ou_E m^{-3}. If this provision is respected, it can be assumed that the installation will not significantly increase the annoying effect of the current reality (i.e. existing odour exposure). This is called the criterion of irrelevance: the insignificance of the expected additional odour exposure.

The results of dispersion calculations are area-related values for the assessment squares according the framework established by GOAA. Hence, to provide results in the classic form of concentration isolines are inadequate to this purpose. Dispersion modelling calculation is performed in line with the procedure described in Annex 3 of TA-Luft by using AUSTAL2000. This is the German regulatory dispersion model set by VDI 3945 – Part 3:2001 (VDI, 2001). If other dispersion models are applied, the authority should be consulted first.

6.2.3. *Austria*

In Austria, the legal system is differentiated between limit values, which have a legal basis, and target values, which are only part of guidelines without legal basis. In this regard, there is no legal limit values to control and manage odorous pollution in Austria. Only for health spa areas, a target value composed by a percentile or exceedance probability of 3% and a concentration threshold C_t of 1 ou_E m^{-3} (similar to Germany). This criterion is generally applied in annual hourly basis (Baumann et al., 2013). The Austrian Academy of Sciences published in 1994 (OAW, 1994) a guideline (no legal significance) with two target values (both must be considered – multi-percentile criterion). However, the C_t is only suggested subjectively:

- Exceedance probability of 8% (92^{th} percentile) for weak odour, and;
- Exceedance probability of 3% (97^{th} percentile) for strong odour.

To apply these values for dispersion model calculations is necessary to interpret the subjective definition of weak and strong odour. For weak odour a C_t of 1 ou_E m^{-3} is assumed and for strong odour a C_t of 5–8 ou_E m^{-3}. Sommer-Quabach et al. (2014) interpreted the Austrian OIC as 1 ou_E m^{-3} and 8%, and 5 ou_E m^{-3} and 3% for residential areas. In Piringer et al. (2015) is reported 1 ou_E m^{-3} and 3% exceedance probability, representative for recreation areas (high odour protection), 1 ou_E m^{-3} and 8% exceedance probability, representative for residential areas mixed with commercial activity (lower odour protection).

Furthermore, the C_t is related to short-term concentrations to mimic the perception of the human nose to odours, usually set between 1 and 5 s. Austrian researchers (Schauberger et al., 2012a; Sommer-Quabach et al., 2014; Piringer et al., 2015) generally consider the duration between each breath as 5 s. Austria propagates a peak-to-mean approach which varies dynamically depending on atmospheric stability and distance from the emission source (Schauberger et al., 2000, 2013; Piringer et al., 2007, 2014, 2015). The variable peak-to-mean concept is used as post-processing tool in the Austrian Odour Dispersion Model (AODM), the regulatory Gauss model in Austria. Recently, Piringer et al. (2016b) have also evaluated the variable peak-to-mean algorithm for the Lagrangian particle diffusion model LASAT. In certain circumstances, the German constant factor of 4 is used. In this case, for hourly mean concentrations the threshold of 0.25 $ou_E\ m^{-3}$ is taken into account considering the concentration of 1 $ou_E\ m^{-3}$ as the short-term limit.

6.2.4. Italy

Italy does not have legislative approaches at the federal level in which specific criteria for environmental odours are included. Concerning odour pollution, the Italian Environmental Code, through the Legislative Decree No. 152:2006, does not set forth any provision. The Integrated Environmental Authorization is the implementation of the European IPPC in the Italian legal system. The states (or “regions” in Italy) have autonomy to regulate on air quality. Despite the following regions, Basilicata (D.G.R. n. 709 del 22/4/2002), Abruzzo (D.G.R. n. 400 del 26/5/2004), Emilia Romagna (D.G.R. n. 1495 del 24/10/2011), Sicilia (D.G.R. n. 27 parte I del 14/06/2002), Veneto (D.G.R. n. 568 del 25/02/2005) present regulation on odours (Brattoli et al., 2015; Morosini et al., 2016), basically the approach is concerning to maximum emission standards for composting and biogas activities. Therefore, these regulations are not detailed herein because odour impact criteria based on time series of odour concentration in ambient air are not provided.

6.2.4.1. Lombardy. The Region of Lombardy, one of the twenty administrative Regions of Italy, published a specific odour regulation (*Deliberazione Giunta Regionale 15 febbraio 2012 - n. IX/3018*) with maximum impact standard based on the frequency with which a given C_t is exceeded, as follows (Regione Lombardia, 2012):

- 1, 3 and 5 $ou_E\ m^{-3}$ set at the 98th percentile on annual basis.

It is defined that 50% of the population perceives the odour at 1 $ou_E\ m^{-3}$; 85% of the population perceives the odour at 3 $ou_E\ m^{-3}$; 90–95% of the population perceives the odour at 5 $ou_E\ m^{-3}$. To convert from hourly concentrations to short-term odour peaks, model outputs are multiplied by $F = 2.3$. Surprisingly, there is no explicit mention to the averaging time that odour peaks are associated. Lombardy regulation indicates that no unanimous agreement about the definition of an appropriate value of F in the scientific literature have been achieved. For this reason, a constant factor is used to depurate the modelling outputs, as far as possible, from the aspects related to the choice parameters of the dispersion model rather than the specific characteristics of the emission scenario (Regione Lombardia, 2012). The guideline is applicable to all activities differentiated between new activities and existing facilities. In the case of new plants, the purpose of the guidelines is to assess, in the design stage, the odour impact produced by the facility in the context of its future location. For existing installations, the strategy to be implemented in the case of overt olfactory issues affecting citizens is to conduct the procedures described in 4 successive phases, called Phase A (field monitoring); Phase B (quali-quantitative characterization of odour impact); Phase C (consent revision); Phase D (proposition of Phase A again). Additionally, the regulation brings guidance and standards for odour impact studies using dispersion modelling, sampling and analysis of odours, evaluation of odour nuisance by the resident population and chemical characterization of odour emissions (e.g. UNI EN 13725:2004, UNI 10796:2000, UNI 10964:2001, UNI 10169:2001, UNI EN 13284-1:2003, VDI 3883:1993, VDI 3940:2006, Method TO-15).

Generally, land uses considered can be divided into agriculture, residential, commercial and/or craft, and industrial areas. Therefore, depending on the area in which the emission source is located, a given intensity of disturbance can or not limit the use of the affected area. In fact, in a residential region where human activities for prolonged periods are common, a mere odour perception can greatly restrict the use of the space, while in an agricultural area the presence of a moderate odour disturbance does not imply that the area cannot be used (Regione Lombardia, 2012). Legally, Lombardy odour policy is valid only for this region. However, other regions of Italy may refer to this guideline when conducting odour impact assessment studies in the absence of their own odour regulations.

6.2.4.2. Puglia. The methodological approach developed to control and manage odours in Puglia is described in detail elsewhere (Brattoli et al., 2015). Regarding maximum impact standards, the criteria are set primarily in a regulation to contemplate odours arising from WWTP, as follows (Arpa Puglia, 2014):

- 1, 2, 3, …$ou_E\ m^{-3}$ at the 98th percentile on an annual basis.

Contour maps that indicate the impact of peak concentration values at the 98th percentile on an annual basis are required, as well as simulation results performed with the meteorological data of the previous two years. As in the Region of Lombardy, a F of 2.3 is used. Modelled scenarios for worst cases are also necessary, with the aim to highlight the scale of the odour impact that identify the worst dispersion conditions. Particularly, scenarios that use the 99.9th percentile need to be consider and the evaluation is carried out in relation to the presence of sensitive receptors. Therefore, we have:

- 1, 2, 3, …$ou_E\ m^{-3}$ at the 99.9th and 100th percentile on an annual basis.

Accordingly, the acceptability of the impacts is based on land use type where the plant is located, and the presence of potentially sensitive receptors, whereas 1 $ou_E\ m^{-3}$ is the concentration at which 50% of the population perceives the odour. As in Region of Lombardy, the regulation provides standards for dispersion modelling, sampling and analysis of odours (e.g. UNI EN 13725:2004, UNI 10796:2000, UNI 10964:2001). For new developments or new abatement units within existing facilities, emission factors can be derived from the technical specifications of the technologies, literature data, consolidated experiences or from orientated reviews for this purpose.

6.2.5. France

The air quality regulation, in France, is primarily regulated by Directive 2008/50/EC concerning ambient air quality and cleaner air for Europe and Directive 2001/81/EC (NEC Directive) on national emission ceilings for certain atmospheric pollutants of the European Parliament. French national legislation is based on the Law No. 96-1236 of 30 December 1996, regarding air and the rational use of energy (LAURE), codified in the Environmental Code. Legislative and regulatory provisions relating to air quality are contained in Title II Air and atmosphere of Book II of the Environmental Code (Articles L220-1 to L228-3 and R221-1 to D228-1) (MEDDE, 2016b).

In this articles the law presents some provisions that brings general concepts about air pollution treating odours in a subjective manner. The Law No. 76-663 of 19 July 1976 is related to classified facilities for environmental protection (*installations classées pour la protection de l'environnement*). This Law is part of the Environmental Code, and it is the basis of the requirements of odour pollution included in the Ministerial Decree of 2 February 1998 and sectorial decrees (MEDDE, 2016a). Specific guidance with maximum immission standards for composting and rendering industries are fixed within these decrees by activity.

For composting processes, the Decree of April 22 April of 2008 (last updated by Decree of 27 July of 2012) sets the technical requirements to be met by composting plants subject to authorization (JORF, 2008). With regard to OIC, Article 26 indicates that:

- For new and existing installations, the odour concentration calculated by a dispersion model at the level of human occupation zones listed in Article 3 within 3 km of fence line of the installation should not exceed the limit of 5 ou_E m^{-3} more than 175 h per year (i.e. 98th percentile).

The assumption of short-term odour concentrations are not pointed out, therefore it can be assumed that the value of F is equal to 1 and odour concentrations calculated using dispersion models are on hourly basis. The dispersion modelling study is conducted at the expense of the operator under his responsibility. However, when the overall emission rate of the facility does not exceed 20×10^6 ou_E h^{-1} or when the installation is located in a particularly low sensitivity zone, it is not mandatory to perform the dispersion study. Article 74 states that the limit values were determined according to the principle of BAT at an acceptable economic cost descried in Article 21. Article 2 establishes that odour concentration is expressed in ou_E m^{-3} determined using NF EN 13725:2003.

Manufacturing processes of animal by-products (i.e. rendering) is covered by Decree of 12 February 2003 – last updated in 30 of April of 2010 (JORF, 2003). Article 28 states that dynamic olfactometric according to NF EN 13725:2003 is used to determine the odour concentration. OIC are defined, as follows:

- For existing facilities, the ambient air odour concentration, calculated within 3 km from the fence line of the installation, should not exceed 5 ou_E m^{-3} applying the 98th percentile;
- For new facilities, the ambient air odour concentration, calculated within 3 km from the fence line of the installation, should not exceed 5 ou_E m^{-3} applying the 99.5th percentile.

There is no mention to peak-to-mean factor. Consequently, it can be assumed that this value is one ($F = 1$) and odour concentrations are simulated on hourly basis. The calculation method used for the dispersion study must take into account the ventilation and thermal conditions of emissions, as well as local dispersion conditions, topographical and meteorological effects. The list of odour sources to be characterized and quantified and choice of the dispersion model are justified by the proponent of the facility. In the case of not realization of the dispersion study, the maximum emission standard for odours must not exceed 1000 ou_E m^{-3} per source, independently of the stack height. Article 46 establishes the frequency of monitoring of odour sources in terms of odour emission rates and the use or not of electronic noses. Article 49 describes the utilization of a nuisance index (Köster index) to olfactory discomfort evaluation perceived by the population in the vicinity of the plant, in accordance with Annex III; the characterization of the overall level of the odour impact variations using odour intensity measurements according to NFX43-103 standard; and the application of continuous monitoring can also be implemented on the basis of continuous measurements of odour concentrations of the sources coupled to a dispersion model. Article 25 says that the removal and discharge of effluents should be based on the BAT at an acceptable economic cost and specific characteristics of the surrounding environment of the facility. More details about odour regulations used in France can be found elsewhere (ADEME, 2005).

6.2.6. Ireland

According to EPA Ireland (2010b), the relevant air quality legislation in Ireland are: Environmental Protection Agency Act 1992 (as amended); Waste Management Act 1996 (as amended); Protection of the Environment Act 2003; Air Pollution Act, 1987; S.I. No. 787 of 2005 Waste Water Treatment (Prevention of Odours and Noise), Regulations 2005. Currently, there is no general statutory odour standard in Ireland related to industrial facilities. However, EPA Ireland (2001) set guidance to intensive agriculture activities, in which the following standards for pigs' production are outlined:

- 1.5 ou_E m^{-3} as target value for all situations;
- 3.0 ou_E m^{-3} as limit value for new pig production units;
- 6.0 ou_E m^{-3} as limit value for existing pig production units.

The 98th percentile is applied on hourly basis ($F = 1$) at sensitive receptors. The target value delivers a general level of protection against odour annoyance for the general public, and is to be used as an environmental quality target for all situations (EPA Ireland, 2001). These criteria were firstly established for pig production, however can be adopted to assess odour impacts from poultry facilities (Hayes et al., 2006). Odour modelling can be carry out using ADMS4 or AERMOD. Supplementary dispersion modelling guidance can be found elsewhere (EPA Ireland, 2010a). Existing facilities need to conduct sampling and analysis to determine odour emission rates (in ou_E s^{-1}). To new facilities, emission factors are given for pigs at different stages in the life cycle. Ireland also follows EU and IPPC directives and recommends the use of BAT.

6.2.7. Netherlands

The Netherlands has a long history of standards, laws, decrees and regulations regarding environmental odours. This history dates from the early 70s.

6.2.7.1. Brief history. In the Netherlands, the first sector to be regulated on a national level specifically to manage odour impacts was the intensive livestock sector. A practical guideline was imposed in 1971 on new and existing livestock operations because the existence of a very large pig production sector. This guideline set minimum separation distance between residential areas and livestock facilities, related to production capacity in terms of the number of animals (Van Harreveld, 2003). In 1984, a quantitative air quality guideline for odours from industrial sources was introduced. This guideline, in turn, was based on measurement of odour emissions using olfactometry, followed by dispersion modelling to predict frequency of exposure odour concentrations in excess of a certain limit value in ambient air over hourly averages. Two types of exposure criteria were set: one more lenient for existing facilities and a more stringent limit for new installations. A more flexible approach were introduced in 1995, and formalized in the Netherlands Emission Guidelines (*Nederlandse Emissie Richtlijn*), the so-called NeR (Van Harreveld, 2003). The system of the NeR was derived from the German TA-Luft. Until 1995, odour issues in environmental permits were regulated at state level. The national policy, as set out in the Revised Odour Policy Note (1994), was modified after discussion in Parliament and further explained in more detail in the letter from the *Minister van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer* (VROM) in June 30 of 1995.

From that moment, odours in the Netherlands started to be regulated nationally. The odour policy, as foreseen in the letter from the VROM (1995), was subsequent elaborated in the Nuisance System (*Hindersystematiek*) that was recorded in 2012 inside the NeR (InfoMil, 2014).

The general policy principle was to prevent and, if not possible, to limit as much as possible nuisance odour. Nevertheless, since January 1, 2016 the NeR has been withdrawn. This process started in 2011 when the Ministry of Infrastructure and Environment and InfoMil in collaboration with the Consultative Group on Industrial Emissions began a reorientation of the NeR. The air emission limits for most chemical compounds emitted by industrial sources were given by the NeR. The NeR was a national guideline (with no legal status) with the purpose of harmonising the environmental permits in the Netherlands concerning the reduction of air emissions. NeR also provided emission factors and exposure criteria (maximum impact standards) for specific odour-emitting activities. Despite the NeR did not have the force of law, odour impact assessments that deviate from the methodology proposed in this guide used to be clearly justified and approved by the relevant authorities. The NeR guideline used to provide OIC according to the offensiveness of the odour. Therefore, limits were source-specific with more stringent criteria applied to sources with more offensive odours. Odour concentration threshold varied from 0.5 ou_E m^{-3} to 25 ou_E m^{-3} and the percentiles from 98th to 99.99th. Peak odour concentrations were not addressed by the usage of the peak-to-mean concept (hourly mean values were taken into account). Discontinuous sources (i.e. emissions during a limited number of hours per year) were not only tested against the baseline 98th percentile (suitable for evaluating continuous sources) but also with higher percentiles.

The industrial activities covered with odour immission criteria in Section 3.3 of the NeR were grass dryers, livestock feed industry, bakeries and pastry, slaughterhouses, meat processing, cocoa beans processing industry, coffee roasters, breweries, asphalt mixing plants, composting of green waste and composting of organic waste. When still active, the special rules of section 3.3 of the NeR were canceled for some industries because of a BREF was elaborated for the industry and included in the Activities Decree or because the measures described were not considered BAT anymore (InfoMil, 2014). The OIC for industries within the NeR used to be set over hourly averages on an annual basis, as follows:

- Forage dryers:
  - o 2.5 ou_E m^{-3}, 98th percentile, residential areas or other odour-sensitive locations;
- Livestock feed industry:
  - o 1.4 ou_E m^{-3} for existing facilities and 0.7 ou_E m^{-3} for new facilities, 98th percentile, residential areas or other odour-sensitive locations;
  - o Based on the local conditions the 95th percentile can be accepted;
- Bakeries and pastry:
  - o 5 ou_E m^{-3}, 98th percentile, residential areas or other odour-sensitive locations;
- Slaughterhouses:
  - o 1.5 ou_E m^{-3}, 98th percentile, odour-sensitive locations;
  - o Between 0.55 and 1.5 ou_E m^{-3} relevant authorities can decide if measures are necessary; < 0.55 ou_E m^{-3} measures are not necessary;
- Meat processing:
  - o 2.5 ou_E m^{-3}, 98th percentile, odour-sensitive locations;
  - o Between 0.95 and 2.5 ou_E m^{-3} relevant authorities can decide if measures are necessary; < 0.95 ou_E m^{-3} measures are not necessary;
- Cocoa beans processing industry:
  - o If the highest odour concentration in residential areas or other odour-sensitive locations at the 98th percentile is:
    - ▪ >2.5 ou_E m^{-3}, then after modification/expansion of the installation the odour levels should not exceed that highest value;
    - ▪ >5 ou_E m^{-3}, then the previous provisions apply and in principle a maximum of 5 ou_E m^{-3} as environmental reference is used;
    - ▪ ≤2.5 ou_E m^{-3}, then after modification/expansion of the installation the odour levels should not exceed 2.5 ou_E m^{-3};
- Coffee roasters:
  - o 3.5 ou_E m^{-3} for existing facilities, 98th percentile, odour-sensitive locations;
  - o For new facilities the acceptable level will be lower;
- Breweries:
  - o 1.5 ou_E m^{-3} for new and existing facilities, 98th percentile, residential buildings or other odour-sensitive locations;
  - o When because of an existing brewery, the odour concentration exceeds 1.5 ou_E m^{-3} at the 98th percentile of hourly values in a year, then measures should be taken with a minimum abatement efficiency of 85%;
  - o Only applicable to breweries with a production capacity greater than 200,000 hl/year;
- Asphalt mixing plants:
  - o 1 ou_E m^{-3} at the 98th percentile and 5 ou_E m^{-3} at the 99.99th percentile for new facilities;
  - o 2 ou_E m^{-3} at the 98th percentile and 10 ou_E m^{-3} at the 99.99th percentile for existing facilities;
  - o For situations where the above values are not reasonably feasible or receptors are located in an area of less protection, may be permitted up in consultation with the competent authority the following limits: 5 ou_E m^{-3} at the 98th percentile and 25 ou_E m^{-3} at the 99.99th percentile;
- Composting of green waste:
  - o 1.5 ou_E m^{-3} at the 98th percentile for new and existing facilities;
  - o 3 ou_E m^{-3} at the 99.5th percentile and 6 ou_E m^{-3} at the 99.9th percentile are also normative;
  - o Only applicable for plants with production capacity exceeding 20,000 tons/year;
- Composting of organic waste:
  - o 1.5 ou_E m^{-3} for new facilities or 3 ou_E m^{-3} for existing facilities, 98th percentile; odour-sensitive locations.

Despite the NeR has been withdrawn, these limits are presented in Table 3.

6.2.7.2. Actual moment. In the Netherlands, the European environmental directives related to air pollution are implemented in the Environmental Management Act (*Wet Milieubeheer*) and the Environmental Activities Decree (*Activiteitenbesluit milieubeheer*). The Industrial Emissions Directive (IED 2010/75/EU) which regulates emissions from large industrial sources is also implemented in the Activities Decree. This Directive sets rules for large combustion plants, waste incineration plants, VOC solvents and IPPC installations. Emissions that are not regulated by the general binding rules of the Activities Decree are subject to permits.

The NeR was split into a normative part and an information part. The normative part was amended into the Activities Decree since January 1, 2016. The informative part will remain available as an information document, known as Information Document on Industrial Emissions (*Informatiedocument industriële Emissies* – IdIE), *NeR: wegens succes opgeheven* and in the *InfoMil Perspectief*. Article 2.7a of the Activities Decree defines the general rules about odours.

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

It mentioned that activities may not cause any nuisance. Only when nuisance is unavoidable, the odours should be reduced to an acceptable level, arranged by local authorities.

Since January 1 of 2007, odours from livestock farms are addressed in the Odour Nuisance and Livestock Farming Act (*Wet geurhinder en veehouderij* – Wgv) with national coverage (VROM, 2006b). The Wgv is the reference for environmental permits in the aspects related to odour nuisance from agricultural livestock production. The Activities Decree (§ 3.5.8) also sets out provisions in this respect. Basically, the purpose of the Wgv is to provide minimum separation distances and maximum impact standards in sensitive receptors to avoid odour impacts.

The general principle of the Dutch odour policy is to minimize odour pollution and prevent new pollution. This principle, together with the use of the BAT, is the heart of the odour policy in the Netherlands. Additionally, regional and local authorities can perform adjustments in the standards because they, as a local authority, can take into consideration relevant (local) interests to reach an acceptable odour condition as part of a sustainable quality of the living environment.

6.2.7.3. Dutch standards. In the Netherlands, since 2004, odour thresholds are measured according to the European standard EN 13725:2003 (Klarenbeek et al., 2014). The European norm was implemented in the country as the NEN-EN 13725:2003. Olfactometric analysis were performed using the Dutch standard NVN 2820:1995/A1:1996 nl (Air quality - Sensory odour measurement using an olfactometer). By definition, the conversion between these standards is 1 $ou_E = 2$ ge (*geurconcentratie*). The NTA 9065:2012 nl (Air quality - Odour measurements - Odour measurement and calculation) describes a standardized approach for performing odour investigations; references to the NTA 9065 are made, for example, within the Activities Decree and the Odour Guide. The NTA 9055:2012 nl (Air quality - Electronic air monitoring - Odour (nuisance) and safety) sets requirements to the application of electronic noses. The hedonic value (H) of an odour is determined by a panel according to NVN 2818:2005 nl (Odor quality - Sensory determination of the hedonic tone of an odour using an olfactometer). This is a relationship between suprathreshold (perceptible) odour concentration and the degree of (un)pleasantness. Panelists express the pleasantness based on a 9-point scale raging from $H = -4$ (extremely pleasant) to $H = +4$ (extremely unpleasant). The relationship between the odour concentration plotted on a logarithmic scale and the hedonic value is approximated as a straight line. From the regression equation, the odour concentrations can be calculated in which the hedonic values are equal to the criteria established in regulations for compliance. The Guide to the New National Model (*Handreiking Nieuw Nationaal Model* – NNM Guide) sets requirements for air quality licensing procedures, including odour studies. Basically, the NNM Guide describes the transport and dilution of substances in the atmosphere based on the Gaussian plume concept (InfoMil, 2016e, d). Usually, ten years of meteorology are used for dispersion modelling (period from 1995 to 2004, according to NTA standard 9065).

6.2.7.4. Odour within the Activities Decree. As previously mentioned, the NeR was implemented within the Activities Decree. The Activities Decree distinguishes industries between type A (no notification obligation), B (with notification obligation) and C (mandatory environmental license). Type C includes industries with an IPPC installation and industries without an IPPC installation. For each type of industry different procedures apply. The conditions of the licensing process is defined in the Odour Guide (*Handleiding geur: bepalen van het aanvaardbaar hinderniveau van industrie en bedrijven* (*niet veehouderijen*)) to determine the acceptable level of nuisance from industries and companies, except the livestock sector (InfoMil, 2016b). The Odour Guide is one of the IdIE manuals, which provides an explanation of the odour requirements of Article 2.7a (it defines the general rules about odours) of the Activities Decree. A separate page discusses the odour aspects that involves the authority in determining the acceptable level of nuisance. This is based on the Nuisance System from the NeR. The Odour Guide also brings the mandatory application of BAT and a schematic diagram to determine the appropriate odour regulations that apply in a given situation.

OIC are described in Article 3.5b of the Activities Decree for WWTP at the 98th percentile (VROM, 2007):

- WWTP built after February 1, 1996:
  - o 0.5 $ou_E\ m^{-3}$ in residential areas or sensitive receptors;
  - o 1 $ou_E\ m^{-3}$ in industrial or business parks or outside urban areas.
- WWTP built before February 1, 1996:
  - o 1.5 $ou_E\ m^{-3}$ in residential areas or sensitive receptors;
  - o 3.5 $ou_E\ m^{-3}$ in industrial or business parks or outside urban areas.

In addition, OIC are also provided for livestock activities in Article 3.115 of the Activities Decree. More details in this regard can be seen below.

6.2.7.5. Odour in the livestock sector. In the Netherlands, the issue of odours in animal husbandry systems is governed by the Wgv (VROM, 2006b) and the Activities Decree, as described previously. Article 3 of the Wgv states that an environmental permit is denied, with regard to livestock farming, if the odour emitted from that facility in an odour-sensitive object (i.e. sensitive receptor) exceeds:

- 3 ou within a concentration area, within the built-up area;
- 14 ou within a concentration area, outside the built-up area;
- 2 ou outside a concentration area, within the built-up area;
- 8 ou outside a concentration area, outside the built-up area.

Independently, the minimum separation distance between livestock farm and sensitive receptor which is part of another livestock farm, or if after March 19 of 2000 has ceased comprising part of another livestock farm, must be at least 100 m within the built-up area and must be at least 50 m outside the built-up area. Article 4 sets the same minimum separation distances for the categories of animals which no odour emission factor has been established. These values can be understood as targets to be met. This is because in Article 6 a municipal ordinance may stipulate that within a part of the municipality's territory other values can be applied, as follows:

- 0.1–14 ou within a concentration area, within the built-up area;
- 3–35 ou within a concentration area, outside the built-up area;
- 0.1–8 ou outside a concentration area, within the built-up area;
- 2–20 ou outside a concentration area, outside the built-up area.

A municipal ordinance may stipulate that, within a part of the municipality's territory, a different distance is applicable in respect with the distances provided in Article 4 with the understanding that this value must be at least 50 m within the built-up area and at least 25 m outside the built-up area.

The Wgv is used in conjunction with the Activities Decree, where in the Article 3.115 the 98th percentile is cited as the frequency value in which the limits of the ambient odour concentration are determined. Moreover, the demands of the Wgv are largely reflected in section 3.5.8 of the Activities Decree. Comparatively, the odour limit values for livestock are considerably more flexible than those in industrial sectors.

The Guide to odour annoyance and livestock farming (*Handreiking geurhinder en veehouderij*) provides an explanation of the Wgv. It also brings a phased plan for preparation of an impact study under the provisions of Article 6 of the Wgv (InfoMil, 2016c). The Regulation on odour nuisance and livestock farming (Regeling geurhinder en veehouderij – Rgv) carries a range of topics to clarify the provisions of the Wgv. The Rgv includes odour emission factors, the utilization of the dispersion model V-Stacks and how distances are to be determined. Additionally, it provides minimum distances for fur-bearing animals (VROM, 2006a). In summary, the Wgv replaces the use of rigid separation distances by introduction a prescribed odour dispersion model that calculates odour levels at the 98th percentile in sensitive receptors. Four different categories of odour-sensitive areas are distinguished because of two location-dependant criteria: (i) is the sensitive receptor inside or outside the built-up area? (ii) is the sensitive receptor inside or outside a livestock concentration area? A maximum admissible odour exposure is established for each of these four categories. The calculation of the odour emission rate is a key input parameter for dispersion modelling. This calculation can be accomplished by multiplying the number of animal places by the corresponding standard odour emission rate for that specific animal category and housing system. For each animal species or category, a standard odour emission rate has been detailed which is expressed as ou_E (animal place s)$^{-1}$ (Melse et al., 2009).

6.2.7.6. Regional odour policy for industrial activities. Local governments, especially provinces, can give regional interpretation to the Dutch odour policy. This is described in the Local odour policy (province) Section – *Lokaal geurbeleid (provincie)* – of the Odour Guide (InfoMil, 2016b). In this regard, for instance, the provinces of Flevoland, Gelderland, Groningen, North Brabant, Overijssel, Zealand and South Holland have their own odour regulatory framework. Usually, the odour regulations from these provinces do not apply to situations in which binding agreements brought other rules and guidelines as, for instance, the Wgv (for livestock activities) and specific provisions for a certain industry sector described within the Activities Decree. Nevertheless, every regulation should be foremost checked to confirm its applicability. An overview of the OIC used in the provinces previously cited is presented below (InfoMil, 2016a).

6.2.7.7. Flevoland. Flevoland regulates on odours in the Policy rules for the assessment of odour nuisance 2008 (*Beleidsregels voor de beoordeling van geurhinder 2008*). This regulation indicates how odour nuisance in the environmental aspect is addressed and should be used for planning purposes. Independently, the requirements of permits must always be based on the use of the BAT. The acceptable level of nuisance for continuous emission is checked against hedonic values ($H = -1$ and $H = -2$) in accordance with NVN 2818:2005. The level of protection is defined for new and existing facilities, sensitive receptors as odour-sensitive objects, less odour-sensitive objects and non-sensitive locations. The limits are set on hourly basis ($F = 1$) at the 95th, 98th and 99.5th percentile depending on the type of the development and location of receptors. Discontinuous sources are assessed against the 95th, 98th, 99.5th, 99.9th and 99.99th percentiles with factors for conversion between the percentiles corresponding to 0.6, 1, 2, 4 and 10, respectively. The relatively highest value of any percentile is considered normative with the exception of the 99.99th percentile, which is always involved only as indicative of the impact study. According to the Flevoland odour regulation, this approach is conducted because odour-peak concentrations may arise particularly in discontinuous sources and close to high stacks.

6.2.7.8. Gelderland. The Gelderland odour policy (*Gelders geurbeleid*) focuses on industrial companies for which the province has a legal responsibility in terms of licensing and enforcement. OIC are given in the document entitled Odour policy in environmental permits Gelderland 2009 (*Beleidsregels geur in milieuvergunningen Gelderland 2009*). Acceptable level of nuisance is based on hedonic values classified into the following categories: very annoying (<1.5 ou_E m^{-3}), annoying (1.5–5 ou_E m^{-3}), little annoying (5–15 ou_E m^{-3}), not annoying (>15 ou_E m^{-3}) with a $H = -2$ associated with the odour concentration. The criteria are divided into target, guideline or upper limit values with differences in the level of protection on the basis of the land use. Therefore, the level of protection is dependent on the function of the area in which the receptors are located. Inside industrial areas the tolerable odour impact can be higher than in residential areas. This principle has led to a breakdown of the assessment framework in two land use categories: residential/rural areas and industrial areas. A distinction is also taken into account for existing or new facilities. Existing situations are compared to the guideline value or the upper limit value. For existing situations, in principle, odour levels are permitted up to the upper limit. In the case of new situations, the target value and the guideline value come into play. In this case, odour levels are permitted up to the guideline value. The application of the BAT is the principle of licensing in any case. If a facility generates odours with a different nature (different hedonic classes), those effects should be taken into account by considering the relative contributions of immission level. For continuous sources, the values are expressed at the 98th percentile. Discontinuous sources are tested against the 95th, 98th, 99.5th, 99.9th and 99.99th percentiles. However, general practice states that the 99.5th, 99.9th percentiles are commonly used for compliance, in addition to the baseline 98th percentile. The C_t varies from 0.05 to 50 ou_E m^{-3} as a function of the protection level.

6.2.7.9. Groningen. Groningen defined the odour policy in Annex 1 of Licensing Policy, Monitoring and Enforcement 2013-2016 Groningen province (*bijlage 1 van Beleidsregel Vergunningverlening, Toezicht en Handhaving (VTH) 2013-2016 provincie Groningen*). This regulation explains how Groningen deals with practical implementation of permitting, monitoring and enforcement for companies. The approach distinguishes sensitive receptors with a high and a low level of protection and new and existing facilities. The H applied range from −0.5 to −3. Therefore, depending on the desired level of protection the value of H is set so that the odour concentration associated with this H can be determined (NVN 2818:2005). Consequently, the limit not to be exceeded is established. Odour impacts are primarily checked against the 98th percentile over 1-h averages. Additionally, to assess odour-peak concentrations the 99.5th (factor 2) and 99.9th (factor 4) percentiles are used. The relatively highest value of any percentile is considered normative. In the cases where no data on hedonic values are available, odour impact assessment should be based on 0.5 ou_E m^{-3} at the 98th percentile. The acceptable level of nuisance must not be exceeded using maximum odour emission rate of the source. The application of the BAT is also considered during the permitting process. For information only, the *Convenant Integratie Milieu en Ruimtelijke ordening (IMR) Suikerindustrie 2008* established specific odour criteria (1.5 ou_E m^{-3} at the 98th percentile) for the sugar industry in the Groningen province.

6.2.7.10. North Brabant. Presently in North Brabant, odours are regulated by the Policy rules of review on odour nuisance in environmental permits for industrial companies in North Brabant

(*Beleidsregel beoordeling geurhinder omgevingsvergunningen industriële bedrijven Noord-Brabant*). The regulation of North Brabant uses the hedonic value H = −1. Before the immission level is calculated using a dispersion model, the odour emission rates first need to be corrected numerically by the hedonic value (H = −1) associated to the source. Calculations are based on a "hedonic weighted ou_E per unit of time", expressed in ou_E(H) h^{-1}. For instance, if a source has an odour emission rate of 630 Mou_E h^{-1} and an odour concentration of 7 ou_E m^{-3} at H = −1, then the hedonic weighted odour emission rate is 90 Mou_E(H) h^{-1} (as a result of 630 Mou_E h^{-1}/7 ou_E m^{-3}). Therefore, dispersion modelling results are expressed as ou_E(H) m^{-3} and compared against the criteria set for North Brabant. The assessment framework includes guideline values and upper limit values on the basis of 98^{th} percentiles and 99.99^{th} percentiles for new and existing activities located in residential, mixed and other areas. The concentrations thresholds vary from 0.5 to 100 ou_E(H) m^{-3}. The Odour Guide (InfoMil, 2016b) contains an example of how the approach of North Brabant is conducted.

6.2.7.11. Overijssel. The province of Overijssel formulated its regulation in the Policy rule on odour nuisance (January 2007) (*Beleidsregel geurhinder (januari 2007)*), which is part of the document Assessment framework for permitting Wm (*Toetsingskader vergunningverlening Wm*). The odour impact criteria applied in Overijssel is identical to Gelderland.

6.2.7.12. Zealand. Odours are addressed in Zealand in the Odour Guide Zealand Province (*Handreiking Geur Provincie Zeeland*). The same principle of C_t dependant on the hedonic tone are applied. The H is defined as equals to −1. The 95^{th} and 98^{th} percentiles of the 1-h mean concentrations are extracted. Discontinuous sources are evaluated on the basis of a higher percentile value (between 98^{th} and 99.99^{th}). In certain circumstances a H = −2 may be applied as a more restrictive criterion. The level of protection is differentiated between new and existing facilities and sensitive receptors and less sensitive receptors.

6.2.7.13. South Holland. Odours are regulated in South Holland by the Policy Memorandum of Odour Nuisance in South Holland province (*Beleidsnota Geurhinderbeleid provincie Zuid-Holland*). The policy is aimed at prevention and control new or existing odour nuisance from industrial activities. The use of the BAT is the first rule that must be followed. In the assessment process for determining the acceptable level of nuisance the following two limits are expressed in contour plots: (i) serious nuisance border: odour pollution (in OU_E m^{-3} at a certain percentile) which is probably over the serious odour nuisance. Above this condition, odour nuisance in sensitive receptors is beforehand unacceptable; (ii) lower limit border: the odour pollution (in OU_E m^{-3} at a certain percentile) below which the odour nuisance is negligible (0% annoyance). From this value is assumed that the odour nuisance starts. The criteria are defined according to the type of odour at a higher or lower concentration than 5 OU_E m^{-3} associated with a H = −2; continuous or discontinuous emission; lower limit border and serious nuisance border. The permissible C_t varies from 0.5 OU_E m^{-3} at the 98^{th} percentile to 25 OU_E m^{-3} at the 99.99^{th} percentile. The limits are set over 1-h mean values. The type of receptors are divided into most odour-sensitive objects, less odour-sensitive objects, and slightly odour-sensitive objects. In the central zone of the Rijnmond conurbation a local odour approach was tailored mainly to avoid cumulative impacts due to clusters of odour sources in this port and industrial area. Annex 5 of the document *Geuraanpak kerngebied Rijnmond* describes the procedure used.

6.2.8. Spain

Spain has no specific instruments to legislate on odours at the federal level. Generally, odours are treated subjectively in federal environmental Laws. The Spanish regulation is still incipient in this regard, and is based on municipal ordinances or activity licenses.

6.2.8.1. Catalonia. Specifically, in Catalonia, the Department of Environment and Housing produced in 2005, a draft of Law against odorous pollution (Generalitat de Cataluña, 2005). Since then, efforts were put in the development and improvement of this document. Such efforts include the addition of new assessment tools used in other countries and conducting odour measurement campaigns in different facilities to check the adequacy of this future standard for the reality of the Spanish territory (CNIC, 2007). However, to date, nothing consolidated was established. According to the Draft, for existing activities the emissions associated with odour-generating sources are measured using the standard UNE-EN 13725:2004. For new activities, the estimation of the emission rate is obtained by applying emission factors. Objective target values of odour immission are applied in residential areas, as follows:

- 3 ou_E m^{-3} for waste management, rendering of animal by-products, distillation of animal and vegetal products, slaughterhouses, paper and pulp industry;
- 5 ou_E m^{-3} for livestock, processed meat, smoked food, rendering of vegetal by-products, treatment of organic products, wastewater treatment plants;
- 7 ou_E m^{-3} for roasting and processing coffee or cocoa facilities, bread ovens, pastry and cookies, beer, production of flavors and fragrances, drying plant products, other activities of Annex 1 of the Draft.

Therefore, the limits are designated by offensiveness. The less offensive the odour is, higher the tolerable level of the C_t. The 98^{th} percentile is applied to the hourly mean concentrations during a year ($F = 1$). Dispersion models used to estimate the impact on the receptors (immission protection) are those recommended by the appropriate regulatory developments. It is considered an odorous pollution if a C_t in ambient air is above 10 ou_E m^{-3}, which leads to nuisances, or if the target criteria do not present compliance. The acceptability displays general character: an activity is compatible with the environment if the odour immission values calculated using dispersion models are lower than those previously established. Otherwise, the activity must propose the adoption of additional corrective measures, to be approved by the authority. Those responsible for the activities, public or private, within the scope of the Draft, must ensure compliance with operational guidelines listed in Annex 2. For the implementation of these procedures, the BAT economically viable need to be considered (DMAV, 2005).

6.2.9. Denmark

In Denmark, two distinct types of installations are considered to assess odour impacts: one focusing on industrial emissions and the other in livestock farms. A detail description of procedures applied in Denmark in respect to air quality emission can be found in the Guidelines for Air Emission Regulation - Limitation of air pollution from installations (DEPA, 2002a). For industries, the odour exposure should not exceed:

- 5 to 10 LE m^{-3} more than 1% of the time (99^{th} percentile).

The Danish odour unit, *lugtenheder* (LE), is somewhat equivalent to ou_E m^{-3} because uses dilutions of the sample until the OPT is reached for 50% of the panel. However, the Danish method utilizes sensitivity factors related to butanol and hydrogen sulphide to determine the OPT. Details of the Danish odour analysis method can be found in Chapter 4 of DEPA (2002b) and directly in the MEL-13 method (*Metodeblad nr. MEL-13, Industri*). Short-term odour peaks of 1-min are considered to mimic the odour sensation of the human nose. When converting from 1-h values to 1-min averages using Equation (4), an exponent $n = 0.5$ is applied. Then, F is equal to 7.75. In Denmark, for regulatory applications a factor of 7.8 is frequently considered (DEPA, 2002a; Olesen et al., 2005). This factor is used over all stabilities, wind speeds, distances and source configurations. The percentile value is set monthly, which means that calculations must be carried out for 12 months of the year. Even if emissions occur only for part of the year, compliance is verified against the highest value of the 12 months applying the 99th percentile over 1-min averages. The impact is evaluated outside the property boundary in residential, commercial areas, industrial and housing in rural areas. Typical maximum emission must be used for all hours in the year. The Danish dispersion model, *Operationel Meteorologisk Luftkvalitetsmodel* (OML), is the regulatory air quality model applied for dispersion modelling. The criterion usually forms the basis for the design of stack heights. DEPA (2002a) also sets a maximum odour emission rate, as follows: "at first, the limit value for emissions of odours can be set at 4000 LE Nm^{-3} at the actual concentration of oxygen. However, in some cases, for technical or financial reasons, it may be necessary to set a higher limit value. In such cases more than 95% purification or abatement should be required". The odour immission limits fixed for industries in Denmark are currently under review by DEPA. They will be updated in the near future. Additionally, immission limits for chemical substances are also applied through the application of the Danish C-values, which for some gases are based on the odour annoyance. OML is used to calculate hourly averages. Then, the monthly 99th percentile during a year is extracted. Results must comply with the C-value everywhere outside the property line. Typical maximum emission must be used for all hours in the year. For some chemicals, intermittent emission can be accounted for by adjusting the C-value (see section 3.1.8 of DEPA (2002a)).

For livestock activities, the Consolidated Act on Livestock Farming Environmental Approvals (The Act No. 1572 of 20 December 2006) and the Order amending the Order on permits and approvals etc. for livestock farms (The Order No. 294 of 31 March 2009) are the principal regulations. Separation distances are determined using both the Technical Report on New Odour Guidelines for Livestock (guidance on permits and approvals for livestock farms) and the Guidelines for the Assessment of Odour and Limitation of Nuisance from Animal Housings. In the first guide, OML model is applied (Miljøministeriet, 2006) and in the latter the *Foreningen af Miljømedarbejdere i Kommunerne* – FMK model (Miljøcenter, 2002). These guidelines provide emission factors depending on the animal categories, recommendations about the usage of the dispersion models and odour exposure criteria. In line with the two guidelines, the separation distance is established on a case-by-case basis according to the longest distance calculated. The odour exposure criteria set in the Technical Report on New Odour Guidelines for Livestock (Miljøministeriet, 2006) and deliberate in the Order No. 294 of 31 March 2009 (DEPA, 2009), besides being also outlined in the Order BEK nr 291 af 06/04/2011 and Order BEK nr 1172 af 04/10/2013, differ depending on land use. These criteria are set, as follows:

- 5 ou_E m^{-3} for existing or future urban areas and recreational use;
- 7 ou_E m^{-3} for a conglomeration in a rural zone (six or more residential buildings);
- 15 ou_E m^{-3} for establishment, expansion or modification of individual properties.

The limits are applied exclusively under impact assessment studies for the establishment, expansion or modification of livestock farms, including animal housings. Results in terms of the maximum monthly 99th percentile over 1-h mean values are requested. Until the beginning of 2014, Kastrup meteorological data from 1976 was used only, which is standard in the software associated with OML calculations. However, OML in the beginning of 2014 expanded and, since august of the same year, the model is able to perform simulations based on the 10 years of meteorological data from Ålborg. With respect to permitting for livestock holdings, this is particularly important in the context of Danish regulations (Miljøstyrelsen, 2011). The DS/EN 13725:2003 is the national standard applicable for measurement of odour concentration of air samples.

6.2.10. Norway

In Norway, odours are addressed under the Pollution Control Act (Act of 13 March 1981 No. 6 Concerning Protection Against Pollution and Concerning Waste), where in Chapter 3 is remarked the provisions for permits for any activity that may cause pollution. Pollution-related nuisance arising from facilities is contemplated in the Pollution Control Act. Nevertheless, odour criteria are not delivered. To assist the County's authorities and the Climate and Pollution Agency (*Klima og Forurensningsdirektoratet* – KLIF) with a quantitative and objective approach to assess odour impacts, the guideline TA-3019:2013 was developed (KLIF, 2013). In general, the guideline sets down a framework for: (i) odour risk assessment; (ii) operating and action; (iii) odour management plan and communication plan.

Operating and action aim to demonstrate the technical planning of the operation and how facilities should be undertaken to minimize odour generation. An odour management plan is a contingency plan. This will help to minimize odour emissions if the facility for some reason stops the production, and support to ensure that normal operation can be restored as quickly as possible. A communication plan consists of a system designed for communication within the company and external communication with neighbors and local communities.

An odour risk assessment should describe the odour potential at every stage of the process; map odour sources, determine odour emission rates and promote the dispersion modelling to simulate odour concentrations in ambient air, both during normal operation and in situations with significant odour emissions and deviations from normal operation. Norwegian odour risk assessment is based on KVALUR method used in conjunction with the standard NS 5814. The purpose of the method is to specify odour risk as an index and indicate whether odour episodes could be considered relevant for the affected receptor. Hence, KVALUR risk assessment tool gives a more detailed insight into each individual odour-emitting source of the facility and the likeliness of the source to cause olfactory nuisances. For each odour source (and the sum of all sources), an odour index should be considered. If this index is less than 0.1, the source is disregarded from further impact assessments. An index greater than or equal to 1 results in great risk that the event will lead to odour episodes at the nearest neighbor. Therefore, this is considered not acceptable and the facility must implement reduction measures. KVALUR method was designed to use in conjunction with dispersion modelling results. Accordingly, a risk index of 1 corresponds to 1 ou_E m^{-3}.

The maximum impact in surrounding homes, hospitals, nursing homes, holiday homes, schools, kindergartens should not exceed either (KLIF, 2013):

- 1 or 2 ou_E m^{-3} at the nearest affected neighbor, defined as the maximum monthly 99th percentile (hourly average).

These C_t corresponds to the former requirements of 5–15 ou_E m^{-3} (1-min mean values). The conversion from hourly to minute concentration values using a constant factor has limited validity because, as previously described herein, this conversion depends on several parameters. Therefore, KLIF no longer recommends this conversion. Generally, the immission limit of 1 ou_E m^{-3} is set for installations located near residential areas. For facilities located in industrial land uses the limit can be fixed at 2 ou_E m^{-3}. The type of business (according to the offensiveness of the odour), geographical location and odour risk are also considered in conjunction. When a facility is located, for instance, inside an industrial park where there are other odour-emitting installations the overall impact of these companies may be so significant that another C_t can be proposed.

For installations with predominantly diffuse emissions (not considering homogeneous emissions from surfaces – area sources) the same immission limits and conditions apply. However, community survey (referenced in VDI 3993) and field assessment (referenced in VDI 3940) are recommended to calculate recognizable annoying odours because dispersion modelling is not appropriate in this case. For modelling, a minimum of one year of meteorology is required to ensured that, at least, meteorological seasonal variations are taken into account. OML, AERMOD and CALPUFF can be applied for dispersion modelling. The Norwegian standard NS-EN 13725 is used for odour measurement.

6.2.11. *Belgium*

In Belgium, the regulation on odour emissions are established at state level. Herein, we present the impact criteria regulatory framework for the Flemish and Walloon region. The objective determination of the odour concentration of a gaseous sample using dynamic dilution olfactometry with human assessors is performed using the national standard NBN EN 13725:2003.

6.2.11.1. Walloon. The environmental legislations of the Walloon region regarding permits are arranged in the Decree of 11 March 1999 (*Arrêté du Gouvernement wallon relatif à la procédure et à diverses mesures d'exécution du décret du 11 mars 1999 relatif au permis d'environnement (4 juillet 2002)).* The activities (or facilities) are divided into three classes according to decreasing importance of their impact. Class 1 brings together the activities potentially most polluting and Class 3 the least polluting. Each facility can be associated with one or more classes related to quantifiable parameters such as the power equipment and processing capacity. In Annex I (administrative form) of the Decree of 11 March 1999 are found generic requirements for odour-emitting activities (e.g. name of the installation generating nuisance, nature of nuisances, preventive measures to reduce odour). More specifically, dispositions are provided for composting installations, including the need to conduct a dispersion modelling study in accordance with Article 27 of the Decree of 18 June 2009 (Gouvernement wallon, 2009). This article states that the odour concentrations calculated in the property line of the nearest dwellings, should not exceed:

- 3 ou_E m^{-3} at the 98th percentile.

This criterion applies for composting facilities with quantity of material stored greater than or equal to 500 m^3. There are no considerations about averaging time, however it is reasonable to assume that hourly mean values are taken into account because short-term odour peaks are not mentioned ($F = 1$).

For livestock activities, the classification of the livestock buildings as class 1, 2 or 3 is a function of the type of animals, the number of animals and the distance between the livestock building and residential area. The calculation of minimum separation distances between livestock buildings and residential housings is accomplished using the methodology described in Nicolas et al. (2008) and proposed as a guideline project for the Walloon Government. This work describes a specific formula to calculate separation distances from piggeries and poultry facilities to sensitive receptors, as follows:

- 6 ou m^{-3} at the 98th percentile for pigs;
- 10 ou m^{-3} at the 98th percentile for poultry.

6.2.11.2. Flanders. In Flanders, there is no comprehensive legal framework to control environmental odours. The odour policy is scattered in various laws, decrees and regulations. Most part of the odour policy aims at reducing odour caused by agricultural and industrial activities to an acceptable level. In particular, the Decree on the environmental permit of June 28, 1985; the Flemish regulations concerning the environmental permits of February 6, 1991 (VLAREM I); the Decree of the Flemish Government concerning general and sectoral provisions relating to Environmental Safety of June 1, 1995 (VLAREM II); and Title XVI of Decree general provisions on environmental policy (better known as the Environmental Enforcement Decree) are relevant in this context. In addition, there are a number of sectoral environmental regulations which may directly or indirectly provide odour mitigation measures and municipalities have the authority to establish local odour polices (LNE, 2006). A summary of the main relevant legal texts and policy documents (in Dutch) can be found elsewhere (LNE, 2010).

In the Flemish region, field inspections were developed for estimating the total emission rate of odour-emitting sources. This technique is based on the determination of the extent of the perceivable odour plume downwind of the source, combined with reverse dispersion modelling. The sniffing method is standardized in a code of good practice (Bilsen et al., 2008). The results of the field survey are expressed as sniffing units per cubic meter (su m^{-3}, or se m^{-3} from *snuffeleenheden*), which represents the minimum amount of the odorant, present in 1 m^3 of air, with the capacity to generate an identification response to some odour experienced by a panel member in the field conditions. The concept of sniffing units is similar to odour units, however measured in the field rather than in the laboratory. Basically, the sniffing method requires the determination of the maximum distance at which the odour emitted from the source can be detected by panel members. This distance and the meteorological conditions at the moment of the assessment are used in a Gaussian dispersion model to estimate the total emission rate. In other words, the maximum odour perception distance, observed by the members of the sniffing team, is incorporated in a short-term atmospheric dispersion model to calculate the total odour emission rate backwards. Consequently, a long term dispersion model is applied to calculate the isopercentile contour plots of odour concentrations (in units of su m^{-3} or se m^{-3}). The IFDM and BULMAL models are based on the formulas contained in Appendix 4.4.1 of VLAREM II. The IMPACT is an improved version of these models based on the same basic formulas. Thus, the odour regulatory framework incorporates primarily the plume measurements in the field. The Flemish odour policy considers the use of BAT measures, which are needed to reduce the nuisance to an acceptable level.

The acceptable nuisance level (*aanvaardbare niveau*) is a core concept, and this level is situated somewhere between the null effect level (*nuleffect niveau)*, target (*richtwaarde*), and the level at which there are serious complaints begin to act, or the limit value (*grenswaarde*) (VITO, 2012). The optimum condition occurs in odour concentrations of less than or equal to the null effect level. This level is equivalent to the target. The general guide is based on a hedonic classification of odours at the 98th percentile, as follows: very unpleasant: 0.5 se m^{-3}; unpleasant: 1.0–1.5 se m^{-3}; neutral: 2.0 se m^{-3}; pleasant: 2.5–3.0 se m^{-3}; very pleasant: 3.5–5.0 se m^{-3}. Some of the criteria were derived on the basis of dose-response relationships, and others were based on the type of odour offensiveness of the facility (Van Broeck and Van Elst, 2003; VITO, 2012):

- Biscuit bakery: 5 se m^{-3};
- Cocoa bean processing plant: 4-5 se m^{-3};
- Coffee-roasting factory: 3.5 se m^{-3};
- Brewery, cluster of farms: 3 se m^{-3};
- Vegetable processing plant: 2.5 se m^{-3};
- Paint shop based on wet paint, sugar plant, potato processing plant: 2 se m^{-3};
- Textile finishing plants, biofilters, WWTP aeration basin, composting installations of green or kitchen and garden waste: 1.5 se m^{-3};
- Vegetable oil extraction and processing, composting plant for mushroom substrate: 1 se m^{-3};
- Asphalt mixing plant: 0.5–1 se m^{-3};
- Slaughterhouse, afterburner grass drying, recycling nutrients, effluent and sludge treatment of WWTP: 0.5 se m^{-3};

Therefore, the realization of the assessment framework in highly sensitive receptors for very unpleasant smells is conducted in this fashion:

- $<$ 0.5 se m^{-3}: negligible impact;
- 0.5 $\geq$ 2 se m^{-3}: moderate negative impact;
- $>$ 2 se m^{-3}: strong negative impact.

It can be distinguished three zones that denote the margin of error on the desired levels of protection (target and limit values). For moderate to low sensitive receptors, a more flexible assessment framework is designated. The limit moves up to 10 se m^{-3} at the 98th percentile. Above this value is considered that unacceptable nuisance can be always expected. The assessment framework in which the odour sensitivity of the destination is taken into account for very unpleasant odours is set, as follows (LNE, 2008; VITO, 2012):

- Target values
  - o 0.5 se m^{-3} for highly sensitive receptors;
  - o 2 se m^{-3} for moderate sensitive receptors;
  - o 3 se m^{-3} for low sensitive receptors.
- Limit values
  - o 2 se m^{-3} for highly sensitive receptors;
  - o 5 se m^{-3} for moderate sensitive receptors;
  - o 10 se m^{-3} for low sensitive receptors.

For more neutral odours (e.g. biofilter) the assessment framework is as follows:

- Target values:
  - o 1.5 se m^{-3} for highly sensitive receptors;
  - o 3 se m^{-3} for moderate sensitive receptors;
  - o 5 se m^{-3} for low sensitive receptors.
- Limit values:
  - o 3 se m^{-3} for highly sensitive receptors;
  - o 5 se m^{-3} for moderate sensitive receptors;
  - o 10 se m^{-3} for low sensitive receptors.

For animal husbandry activities, OIC are established based on individual facilities or clusters at the 98th percentile. The criteria for geographically isolated companies is divided between new and existing facilities. For new installations, odour levels should not exceed the following values (LNE, 2008; Willems et al., 2015):

- Target: 0.5 ou_E m^3;
- Limit: 1 ou_E m^3

The target criterion aims at reaching the null effect level regardless of the type of land use. For existing installations, the criterion is considered appropriate at the level of the nearest house (if economically feasible using BAT for the developer), as follows:

- Limit: 1.5 ou_E m^3

Due to the cumulative effects, clusters of livestock facilities are regulated in the following manner:

- Target: 3 ou_E m^3 for all land uses;
- Limit: 3 ou_E m^3 for highly sensitive receptors;
- Limit: 5 ou_E m^3 for residential areas with rural character;
- Limit: 10 ou_E m^3 for rural areas.

These previous criteria were strictly developed for clusters of swine farms. However, all types of animal farms can be assessed in this fashion. Odour emission factors are also provided as a function of animal type and life phase (LNE, 2015).

Moreover, in Flanders, as well as in Walloon, field assessments have been conducting using the future European standard FprEN 16841-2 (plume method). The results of this standard are characteristically used for both to estimate the total emission rate of the facility under investigation because of the plume extent by applying reverse dispersion modelling or to determine a reasonable extent of potential exposure to recognizable odours.

6.2.12. Hungary

Currently, Hungary has no legal limits for assessing the impact of odorous emissions. In Cseh et al. (2010) is suggested C_t values that vary from 3 to 5 ou, based on European regulations, to be used as a target. Nothing is explicitly mentioned with respect to averaging time and the peak-to-mean concept. However, it is reasonable to assume that the criterion is centered on hourly basis (i.e. $F = 1$) or, less likely, it was embedded on the values of C_t. Percentile or probability of exceedance are not suggested, despite a mention that, internationally, the most widely used value is the 98th percentile. The model commonly used for air quality modelling practice is called OT. This model was developed from the HNS-TRANSMISSION model. The OT was settled to simulate the odour dispersion discharged from livestock activities, landfills, and factories (Cseh et al., 2010).

6.3. Oceania

6.3.1. Australia

OIC used in Australia vary considerably mainly because the states have autonomy to develop and propose individual air quality standards. In Australian states the odour impacts are assessed at the receptors, except in Victoria where the impact is assessed on the fence line of the odour-emitting facility and Tasmania at or beyond the fence line. All states adopt the Australian/New Zealand Standard 4323.3:2001 for odour measurement by dynamic olfactometry (AS/NZS, 2001) and each state has its specific modelling guide with directions and recommendations in this regard (e.g. DEC (2005)).

The steady-state Gaussian plume model AUSPLUME (Lorimer, 1986) is one of several regulatory models used in Australia. However, the model has not been maintained in recent years and the current version AUSPLUME V6 dates from 2004. Consequently, AUSPLUME is less technically advanced compared to more modern Gaussian plume models, such as AERMOD that receive regular updates and improvements from the USEPA. However, it remains an acceptable model for regulatory assessments in some Australian states.

As of 1st of January 2014, AERMOD has replaced AUSPLUME V6 as its regulatory steady-state Gaussian dispersion model in the state of Victoria. Other states are considering this transition as well for assessment situations where the use of steady-state Gaussian plume modelling is appropriate. All states recommend the use of more advanced dispersion models to better account for situations involving low wind speeds and complex terrain. Dispersion models commonly used for this purpose include TAPM V4 (Hurley, 2008) and the USEPA approved puff model CALPUFF.

6.3.1.1. Queensland. In Queensland, proponents of new facilities may undertake an impact assessment with relevant inputs of emissions and local meteorology to an air dispersion model in order to provide estimates of the likely odour impacts in the surrounding environment. The inputs should be as detailed as possible, reflecting any variation of emissions with time and including at least a full year of representative hourly meteorological data. The modelled odour concentrations at the most exposed existing or likely future off-site sensitive receptors should be contrasted with the following limits:

- 0.5 ou, 1-h average, 99.5th percentile for wake-free stacks;
- 2.5 ou, 1-h average, 99.5th percentile for ground-level sources and wake-affected stacks.

For facilities that do not operate continuously, the 99.5th percentile must be applied to the actual hours of operation. The concentration criterion is based on the default annoyance threshold of 5 ou, and conservative default *F* of 10:1 for wake-free stacks and 2:1 for ground-level sources or wake-affected stacks were considered to translate the results to 1-h value. In this jurisdiction, the percentile value is used as a statistical parameter to filter the extreme values generated by modelling and not meant to be interpreted as allowing nuisance or failure of emission controls (EHP, 2013). Queensland also allows the option of a criterion threshold of “weak” intensity level to be applied for complex mixtures of pollutants with offensive odour.

Queensland sets specific OIC for meat chicken farms. When assessing separation distances, the S-factor methodology should be used for meat chicken farms up to 300,000 birds, and odour dispersion modelling should be used for farms with more than 300,000 birds. Odour dispersion modelling can also be used for meat chicken farms with less than 300,000 birds, if separation distances are less than required by the S-factor methodology. Modelled odour levels should be assessed against the following criteria:

- 2.5 ou, 99.5th percentile, 1-h average for a sensitive land use in a rural zone;
- 1.0 ou, 99.5th percentile, 1-h average for the boundary of a non-rural zone.

The stringent recommendation for a non-rural zone considers a risk-based odour assessment procedure, such as that used in New South Wales (NSW). The value of 1 ou (99.5th percentile, hourly average) is approximately equivalent to the odour performance criterion for urban areas in NSW (2 ou, 99th percentile, 1 s). This recommended criterion is significantly more stringent than the “default” odour criterion generally used in Queensland, as described previously. The guidelines apply to the development of new meat chicken farms and the expansion or modification of existing facilities. The guidelines are not designed to cover poultry farming activity other than meat chicken production. Moreover, egg production is excluded from these guidelines because a significantly different production system is used (DAFF, 2012). Other type of OIC, for individual odorous pollutants, are also defined for Queensland. In this case, impact assessments for single odorous pollutants may be conducted similarly to those for odours using dispersion modelling with the results then compared to odour detection thresholds. Potential shortcomings of this approach is that reported odour detection thresholds of individual chemical species may vary by several orders of magnitude; it may not be clear whether reported values are detection or recognition thresholds; and the methods and reliability of the determinations may be unknown (EHP, 2013).

6.3.1.2. New South Wales. Concerning the New South Wales (NSW), depending on the individual characteristics of a new development and its proposed location, the odour potential can be assessed in different degrees of evaluation. For this reason, in NSW, three levels of impact assessment for odour sources were adopted, conditioning to new, modified or existing activity, regardless of whether the sources are classified as point or diffuse (DEC, 2006b). Level 1 is a screening-technique based on simple calculations considering generic parameters for the type of activity and site. It may be used to assess site suitability and odour mitigation measures for new or modified activities and is mostly suitable for smaller developments in sparsely populated areas as, for instance, a small broiler chicken farm located in a rural area with no existing or likely future sensitive receptors in the surrounding region. Level 2 is a screening-level dispersion modelling technique, which uses worst-case input data rather than site-specific data. This procedure is more rigorous and provides a more realistic prediction of the odour impacts than a Level 1 assessment. It may be used to assess site suitability and odour mitigation measures for new, modified or existing activities. Level 2 assessment can be performed, for example, to determine whether a proposed upgrade and expansion of a sewage treatment plant would result in odour impacts on local population. Level 3 is a refined-level dispersion modelling technique that uses site-specific input data and provide more robust results. Therefore, Level 3 is the most comprehensive and most realistic level of assessment available. It may be used to assess site suitability and odour mitigation measures for new, modified or existing activities. For example, Level 3 assessment using concentrations of pollutants measured at site emission sources could be undertaken to assess whether proposed mitigation strategies would be adequate to reduce odour impacts from a waste oil processing facility, the subject of long-term numerous complaints from n neighbors (DEC, 2006a). The odour policy in NSW also provides a process by which odour assessment procedures for specific industrial sector can be developed (DEC, 2006b; De Melo Lisboa et al., 2014).

The NSW odour framework adopts two types of exposure limits for odour. Ground level concentration (glc) are used for individual and easily identifiable odorous pollutants from point sources and odour assessment criteria are used for complex mixtures of odours from point and diffuse sources.

Glc criteria are selected on the basis of the most stringent of odour or health impacts. Impacts should be reported using an averaging time of an hour. Glc impacts should be reported as 100th percentile (maximum) model predicted concentrations for Level 2 assessments and as 99.9th percentile concentrations for Level 3 assessments.

NSW odour regulation establishes odour criteria from 2 to 7 ou depending on population density, averaged over the nose response time (approximately 1 s). Thresholds should be calculated at the 100th percentile (or maximum) concentration for Level 2 assessments and for not more than 1% of the time over a year (i.e. 99th percentile) for Level 3 assessments. Although an averaging time of the order of 1 s is assumed, in practice modelling is undertaken using a 3-min averaging time. Peak-to-mean factors (*F*) are dependent upon the type of source (area, line, surface wake-free point, tall wake-free point, wake-affected point, volume), atmospheric stability (Pasquill–Gifford classes) and distance downwind of the source (near or far-field). For instance:

- Area sources: $F = 1.9$ applies to E, F stability classes in the far-field ($F = 2.3$ in the near-field) and $F = 2.3$ for A-D stability classes in the far-field ($F = 2.5$ in the near-field);
- Volume and wake-affected point sources: $F = 2.3$ for A–F stability classes in the near-field and far-field.

All *F* values can be found in Table 6.1 of DEC (2005). These *F* are assumed for an idealized situation for a single source in flat terrain where the receptor is located along the centerline of the plume. The ratios do not consider fluctuations away from the centerline, terrain influences or plume interaction from multiple sources (DEC, 2005). The population-dependent approach recognizes that in any sample of the general population there is a spread of odour sensitivities. In larger groups, the possibility of there being very sensitive individuals increases and hence it is considered appropriate to reduce the risk of adverse effects with more restrictive criteria. Odour performance criteria are applied at the nearest existing or likely future offsite sensitive receptors based on affected population (DEC, 2006b). NSW also considers impact assessment criteria for ground level concentrations of individual toxic and odorous air pollutants. Approved methods for the sampling and analysis of air pollutants in New South Wales are described in DEC (2007).

6.3.1.3. South Australia. In the state of South Australia, as well as in NSW, odour criteria are dependent on the population density. The increased possibility of susceptible individuals at a certain location intensifies the potential of complaints, and, therefore, more stringent criteria are applied. The simulated odour levels calculated by dispersion models (3-min averaging time) should not exceed the 99.9th percentile on sensitive receptors, not including houses on the property of the facility. Odour concentration thresholds vary from 2 to 10 ou and population from more than 2000 to less than 12 people, respectively. No guidelines are given to determine the *F* for an integration time that deviates from the 1-h mean value. However, the usage of *F* is regularly addressed by using the NSW Odour Policy.

For example, if an odour-emitting source is placed in an area with a single rural residence to the north and a town of 500 people to the south, then the appropriate criterion is 10 ou for the rural residence and 4 ou for the town and adjoining houses. As a general guide, if the modelled odour levels are half the acceptable level, then the proponent can reasonably expect that the project will remain within acceptable levels of odour in most situations. If the predicted odour levels are double the acceptable criteria, the whole concept of the facility would probably need to be re-examined. Predicted odour concentrations between half and double of the acceptable criteria would justify a general review of the proposed odour abatement systems and even the dispersion modelling study. Criteria for individual pollutants in the air and separation distances for a range of industries are also provided (SAEPA, 2006, 2007a, b).

6.3.1.4. Tasmania. In Tasmania odour design criteria are provided in Schedule 3 of the Environment Protection Policy (Air Quality) 2004 (EPA Tasmania, 2004). If a regulatory authority is convinced that an odour source is causing or is likely to cause an environmental nuisance or material environmental harm, dispersion modelling study should be performed to ensure that the predicted maximum ("worst case") ground level concentration does not exceed 2 ou, based on the 99.5th percentile and averaging time of 1 h. Simulated levels are applied at or beyond the boundary of a facility (whichever is higher) in cases where local high-quality meteorological and emissions data are available. The 100th percentile concentration modelled at or beyond the boundary of a facility applies in cases where such data are not available. There is no specific mention to peak-to-mean factor (therefore, $F = 1$). The criteria are not dependent on population density or other protection levels. Nonetheless, these factors may be considered when deciding whether to apply the design limits. Tasmania also presents standards for individual pollutants in ambient air and maximum emission for stacks. In the case of known individual pollutants, the 99.9th percentile and averaging time of 3-min (unless otherwise specified) are applied when high-quality meteorological and emissions data are available. Otherwise, 100th percentile is used. A list of 123 regulated chemicals are provided in Schedule 2 of the Environment Protection Policy (Air Quality) 2004 (EPA Tasmania, 2004).

Atmospheric dispersion modelling must be conducted using a model approved by the Director of EPA Tasmania in accordance with the draft *Tasmanian Atmospheric Dispersion Modelling Guidelines.* Basically, the dispersion modelling study should consider local terrain and meteorology, effect of background concentrations where applicable, contribution of adjacent sources and the need to preserve the capacity of the local environment to receive future emissions (EPA Tasmania, 2014).

6.3.1.5. Victoria. The EPA from Victoria sets a general criterion of 1 ou, 99.9th percentile over 3-min averaging time for odour assessments. This is applied at and beyond the property boundary for new or expanded sources of emissions such as industrial premises. For industries encompassing intensive animal husbandry production, an integrated set of criteria may be applied to ensure beneficial uses are protected. The set of criteria should include completion of a risk assessment that includes modelling of emissions showing that the predicted maximum odour levels do not exceed 5 ou at the 99.9th percentile over 3-min averaging time at and beyond the fence line. The location of intensive animal industries must be consistent with integrated land use planning, i.e. set within rural zones (EPA Victoria, 2001). Specially, when an assessment is required for broiler production and the development cannot meet the criteria of 5 ou, the use of an odour environmental risk assessment is required. In this regard, the utilization of a risk matrix is recommended rather than the use of a single criterion (EPA Victoria, 2012; ERM, 2012). Post-processing to produce 3-min predictions involves the use of Turner's power law using an exponent $n = 0.2$ (EPA Victoria, 2013b). Hence, a constant peak-to-mean factor $F = 1.82$ is applied. Victoria assumes that the utilization of a single *F* to estimate peak concentrations from mean concentrations will result in conservative values.

Inclusion of background odours is not mandatory for modelling assessments, unless other sources of the same odour are present in that local area. Where adjacent sources of the same type of odour are proposed, then emissions from the adjacent sources must be included. New proposals must demonstrate that best practice management of their emissions will be applied. For individual chemical compounds that are odorous, specific design criteria are established on the concentration at the odour detection threshold of the substance (CASANZ, 2013).

Victoria also provides guidance on recommended separation distances for odour and dust-emitting industries from sensitive land uses (EPA Victoria, 2013c), construction of input meteorological data files for EPA Victoria's regulatory air pollution model (AERMOD) (EPA Victoria, 2013a), the usage of the regulatory air pollution model AERMOD (EPA Victoria, 2013b).

6.3.1.6. Western Australia. The *Environment Protection Act 1986* (EP Act) provides the high-level legislative framework to regulate air pollution including odour emitted from industrial and other sources in Western Australia (WA). At the time of this writing, environmental regulations and policies subservient to this act were undergoing significant reform. The department responsible for licensing, approvals, compliance and enforcement relating to industry emissions and discharges is the Department of Environment Regulation (DER).

DER's Guidance Statement: Regulatory Principles (2015) outlines the overarching regulatory principles that will support and guide the development of its policies and regulations relating to emissions and discharges to air including odour. A key regulatory principle adopted is risk-based assessment. Details of this approach are documented in DER's *Guidance Statement: Risk Assessments* (2016). The DER website (http://der.wa.gov.au) listed its guideline on odour risk assessment as upcoming.

DER has published a *Draft Guidance Statement: Separation Distances*. This draft (not final) document lists separation distances that "are the estimated distances recommended to separate premises and their emissions from sensitive land uses to preserve the beneficial use of the environment" (DER, 2015). Factors considered in determining these distances include gaseous emissions, noise, dust and odour. In most cases the separation distances are fixed, although variable separation distances and case-by-case assessments are referred to for some industry categories and sizes. Separation distance guidelines between industrial and sensitive land uses are also established by the Western Australian Environmental Protection Authority (WA EPA) ((WAEPA, 2005).

Historically, a WA EPA document *Guidance Statement No. 47: Assessment of Odour Impacts from New Proposals* (final status) (WAEPA, 2002) outlined odour impact assessment procedures for new proposals in Western Australia. This document was withdrawn in 2005 and replaced with a short interim guidance until 2010. Both versions of the guidance were supported by the then Department of Environmental Protection's Odour Methodology Guideline (DEP, 2002).

The 2002 (final status) version of the guidance statement documented a 3 step process for assessing new proposals or expansions with the potential to cause impacts at existing sensitive receptor locations or assessing the potential for odour impacts on proposed developments near existing odour sources.

The first (screening) level of assessment compared separation distances between source and receptor against the generic buffer distances listed in EPA Guidance Statement No. 3 (WAEPA, 2005). If this distance was met no further assessment of odour was required.

If the generic buffers were not met proponents could demonstrate acceptability by undertaking screening-level dispersion modelling using a 2 part conservative ("green light") odour criterion of 2 ou, 3 min average (Part A), 99.5th percentile, and 4 ou, 3 min average, 99.9th percentile (Part B) concentrations. If this criterion was met, no further assessment of odour was required.

If the green light criterion was not met, proponents could undertake dispersion modelling using a criterion with a concentration threshold equivalent to an intensity level of "distinct", averaged over 3 min, 99.5th percentile. This would require proponents to undertake and odour intensity study to determine the relationship between concentration intensity for the odour. Proponents were requested to assume that an odour concentration of 7 ou corresponded to a "distinct" odour intensity for poultry farm odours.

Proponents were required to advise if sources were highly intermittent in nature in order that an additional criterion based on a higher concentration percentile could be developed that would reflect the degree of intermittency of the source. Of note is that the multi-percentile criteria listed only applied to sources which could be classified as volume sources, large area sources or strongly wake affected plumes. Criteria were not provided for wake-free stacks. Moreover, no guidance was provided in this document to determine *F* for an integration time that deviates from the hourly mean value.

6.3.2. New Zealand

The first odour modelling guidelines used in New Zealand were developed in the early 90's. That time, a level of 2 $ou_E\ m^{-3}$ (99.5th percentile) was widely regarded as the annoyance threshold for wastewater treatment plants using Gaussian dispersion models. Subsequently, there was considerable debate at the end of 1990 on appropriate modelling guidelines, which resulted in the Good Practice Guide for Assessing and Managing Odour in New Zealand (MfE, 2003). These guidelines, in turn, have been adopted by regional councils (Needham and Freeman, 2009). The Guide provides general direction for the selection of odour-modelling criteria, which ranges from 1 to 10 $ou_E\ m^{-3}$ depending on the sensitivity of the receiving environment. The type of land use can be grouped into three levels of sensitivity: high sensitivity (residential, high density residential, commercial, retail, business, education, institutional, open space, recreation, tourism, cultural conservation, marae); moderate sensitivity (light industrial); and low sensitivity (rural areas, heavy industrial, public roads). The recommended odour-modelling guideline values are defined as follows: high sensitivity during worst-case impacts during unstable to semi-unstable conditions with C_t of 1 $ou_E\ m^{-3}$ (99.5th and 99.9th percentile); high sensitivity during worst-case impacts during neutral to stable conditions with C_t of 2 $ou_E\ m^{-3}$ (99.5th and 99.9th percentiles); moderate sensitivity during all conditions with C_t of 5 $ou_E\ m^{-3}$ (99.5th and 99.9th percentile); low sensitivity during all conditions with C_t of 5–10 ou m^{-3} (99.5th percentile). These limits already include the adjustment to the *F* for all varieties of sources and should be used for simulating the hourly mean concentrations at ground level. The 99.5th percentile is set as the base for impact assessment, nevertheless for sensitive receptors the 99.9th percentile will also be used to support in the evaluation of model results depending on the source type and consistency of emission data. Furthermore, the use of the 99.9th percentile would be more appropriate than the 99.5th percentile when the source operates intermittently and less than 50% of the time, since the peak impacts of infrequent odours in such cases may be the main driver of nuisance (Needham and Freeman, 2009). The 99.5th percentile provides a useful indication of the potential adverse chronic effects, while the 99.9th percentile provides an indication of the potential acute effects due to short-term high concentrations (Freeman and Cudmore, 2002).

In New Zealand, various reference limits in force are based on a C_t between 2 and 5 $ou_E\ m^{-3}$. The C_t of 5 $ou_E\ m^{-3}$ is based on research conducted in controlled laboratory condition and Gaussian dispersion modelling studies. This value is appropriate to offensive odours. In fact, the odour perception of an individual is a complex reaction to FIDOL factors, background odours, and even mental and physical state (Needham and Freeman, 2009). Therefore, the Guide recognizes that other values can be used on a case-by-case basis if properly justified for specific odour sources and the work has been adequately peer reviewed (MfE, 2003). Olfactometry technique used in New Zealand are applied jointly with Australia (AS/NZS, 2001). Modelling recommendations and other types of limits (e.g. complaint and annoyance criteria) are also designated in MfE (2003). A case study of the application of the annoyance criteria using community survey for impact assessment purposes can be found in Brancher and De Melo Lisboa (2014).

An overview of the legislative and policy frameworks for air quality management in Australia and New Zealand, that summarizes Acts, Regulations, Guidelines and Policies administered by each jurisdiction can be found in CASANZ (2013).

6.4. Asia

6.4.1. Japan

Japan developed its own odour standards independently from the rest of world during the 70s and apply them on national level through the Offensive Odour Control Law (Law No. 91 of 1971 – Latest Amendment by Law No. 71 of 1995). The regulation system stipulates two different mechanisms of odour control:

- Concentration of offensive odour substances;
- Odour index.

Authorities can choose either of these two mechanisms and establish three applicable regulation standards corresponding to three types of odour emissions from facilities:

- Regulation standard on the fence line;
- Regulation standard for stack emissions;
- Regulation standard for liquid effluent outlets.

The regulation standards are set according to geographical and demographical conditions. All kinds of facilities within regulated areas are controlled by the law. This applies regardless of type, scale or management organization of business. Densely populated areas and suburbs with schools and hospitals are the typical areas regulated. For the concentration of offensive odour substances, a range of maximum concentrations permitted at ground-level on the fence line of a facility is provided for 22 specified offensive odour substances. On the other hand, the Odour Index is used to quantitatively determine the intensity of odours and can be calculated by multiplying the common logarithm of the dilution rate by the factor 10 (Odour Index = 10 × Log [odour concentration]). The odour concentration is measured using the Japanese triangular odour bag method. Measurements are based on the dilution ratio until the odour cannot be detected any longer using human olfaction. The intensity scale used varies from 0 (no odour) to 5 (very strong) and this criterion is based on the premise that an Odour Index associated with an odour intensity scale ranging from 2.5 to 3.5 (equivalent to 10-21 Odour Index) is deemed acceptable at the site boundary (Iwasaki, 2003; MOE, 2003b, a; Kamigawara, 2003).

6.4.2. China

In China, odours are not regulated under the national ambient air quality standards (GB 3095-2012) released by the Ministry of Environmental Protection (MEP). The Integrated Emission Standard of Air Pollutants (GB 16297-1996), under the Law on the Prevention and Control of Air Pollution, sets emission limits for 33 air pollutants and presents various requirements for the implementation of the standard. Moreover, China has a regulation called Emission standard for odour pollutants (GB 14554-93) that specifies emission standards according to stack height for 8 odorous pollutants (ammonia, trimethylamine, hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, carbon disulfide and styrene) including odour (i.e. the role of chemical compounds within a mixture). Also, maximum concentration limits in ambient air at the facility boundary are set for these 8 odorous pollutants and odour. This standard is applicable to the environmental management of all installations emitting odorous gases and is established for different land uses (termed as class 1, 2 or 3) and for new, existing or extension/rebuilt facilities (MEP, 2016). If the source height is greater than 15 m, then the emission standards apply. Alternatively, if the source has less than 15 m, the immission limits are considered, as follows:

- Class 1: 10;
- Class 2: 20 for new, extension/rebuilt and 30 for existing facilities;
- Class 3: 60 for new, extension/rebuilt and 70 for existing facilities.

In this case, the sampling frequency for continuous emission sources are separated by at least 2 h, collecting a total of 4 samples in order to obtain the maximum value measured. Intermittent sources are selected for sampling within the maximum odour emission rate, not less than 3 samples, among whichever is the maximum value measured. For emission limits, odour criteria are set according to the stack height and maximum emission rate, respectively:

- 15 m: 2000;
- 25 m: 6000;
- 35 m: 15,000;
- 40 m: 20,000;
- 50 m: 40,000;
- $\geq$ 60 m: 60,000.

The unit for odour concentration, in the GB 14554-93 Standard (MEP, 2016), is described as dimensionless, although the Japanese triangular odour bag method is applied to measure odour concentration (GB/T14675-93) and the flow rate is calculated in $m^3\ h^{-1}$. Additional methods are described for the determination of the concentration of the 8 odorous pollutants. Class 1 standards apply to special protection regions such as national parks and historic sites. Class 2 standards apply to residential and mixed areas and Class 3 to special industrial areas.

6.4.3. South Korea

In South Korea, the Malodor Prevention Law (KMOE, 2008) has the aim to ensure that citizens can live in a healthy and pleasant environment by preventing odours emitted due to business activities. According to this Law, the air dilution sensory (ADS) test is recommended as a primary means to assess the level of odour pollution in dilution-to-threshold (D/T) ratios (Kim, 2016). ADS was developed from the Japanese triangular odour bag method. The ADS test is part of a threshold olfactometry procedure in which the central trend of odour index value is derived geometrically for a given odour sample, excluding posteriorly the data sets of extreme cases (Kim and Park, 2008). Under this Law, samples are collected from odour sources (emission limits) or other surrounding areas (immission limits), as follows (Park, 2004):

Maximum emission standard (outlets including stack):

- Facilities in industrial areas: 1000 D/T;
- Facilities in other areas: 500 D/T.

Maximum impact standard (boundaries of facilities including enclosures):

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

- Facilities in industrial areas: 20 D/T;
- Facilities in other areas: 15 D/T.

Moreover, chemical analysis of 22 compounds are subjected to regulation as the major odorants (Kim and Kim, 2014). These chemicals compounds should be measured at critical off-site and emission points.

6.4.4. Hong Kong

The Air Pollution Control Ordinance, Chapter 311/2014, and its supplementary regulations, is the main legislative mechanism to control air pollution from stationary sources in Hong Kong. In this regulation, odours are addressed subjectively as a means of air pollution. The criterion for odour impact assessment is set in Annex 4 (Criteria for Evaluating Air Quality Impact and Hazard to Life of the Technical) of the Environmental Impact Assessment Ordinance Technical Memorandum (EPD, 2011), which is the following:

- 5 ou over 5 s mean values for simulation of odour impacts.

The hourly concentration is converted into 3-min concentration according to a power law relationship dependent on atmospheric stability. Subsequently, a conversion factor of 10 for unstable conditions and 5 for neutral to stable conditions are applied to convert the 3-min concentration to 5-s concentration. In short, to derive the 1-h values to 5-s concentrations, the following factors (*F*) are applied in line with the Pasquill-Gifford stability classes: A and B = 45; C = 27; D = 9; E and F = 8 (EPD, 2016). AERMOD is the recommended model that can be used for simulation of odour dispersion. Compliance with the criterion is established at the nearest sensitive receptors for the highest results calculated (i.e. 100^{th} percentile). Contour plots are also mandatory for indicating the general impacts of emissions over the area of investigation (EPD, 2016). EN 13725:2003 is generally used as reference method for olfactometric analysis. According to Hong Kong Planning Standards and Guidelines, Chapter 9/2014 fixed buffer distances to avoid nuisance in sensitive land uses are also set for certain activities.

6.4.5. Taiwan

The Air Pollution Control Act (APCA) is the basic law governing and promoting air pollution control and prevention in Taiwan. This regulation was initially enacted in 1975 and amended in 2006 and indicates the types of air pollutants including gaseous, particular authority (Tsai, 2016). For odour-related chemicals, ambient air standards are set for NH_3, H_2S, $(CH_3)_2S$, CH_3SH (Chen et al., 2003). Under the authorization of the Act, there are regulations concerning the emission standards of air pollutants (including air toxics) from stationary sources based on specially designated industry categories, facilities, pollutant types or zones (Tsai, 2016). Article 31 of the APCA is related to air pollution activities restrictions in which is not allowed to generating odours during the operation of pollution sources or using organic solvents. According to Tsai et al. (2009), the Taiwan's Environmental Protection Administration (Taiwan EPA) sets maximum allowable ambient odour concentration in this manner:

- 50 D/T in industrial and agricultural regions;
- 10 D/T in residential areas.

The criteria are established at the boundaries of any installation and odour samples are collected in the field to verify compliance. For industrial areas in South Korea the limit is 20 D/T and in other areas 15 D/T, for comparison. Despite the practicality involved, we emphasize that the use of this method is totally vulnerable to meteorological and emission conditions at the time of sampling. Odour concentrations are measured using the standard method of the Taiwan EPA (NIEA A201.10A.), comparable to the Japanese triangular odour bag method (Tsai et al., 2009). The Taiwan EPA makes recommendations on dispersion modelling in the document called Air Quality Models and Simulation Standards. However, this document is aimed at conventional pollutants and dispersion of odours are not detailed.

6.5. Africa and Middle East

6.5.1. South Africa

In South Africa, through the National Environment Management: Air Quality Act, 2004 (Government Gazette, 2005), pollution caused by dust, noise and offensive odours are addressed. In this regulation, offensive odour is defined as any smell which is considered to be malodorous or a nuisance to a reasonable person. Authorities may prescribe measures for the odour control originating from specified activities. Additionally, the occupier of any premises must take all reasonable steps to prevent the odours emission of any offensive odour caused by any activity on such premises (Government Gazette, 2005). Accordingly, in South Africa, at the federal level, no specific standards to regulate on odours are existent.

6.5.2. Saudi Arabia

In Saudi Arabia, atmospheric pollutant levels are regulated by ambient air quality standards. No criteria for odours are set, though. Hydrogen sulphide is contemplated as an odorous compound and limits in ambient air are stablished for this pollutant (PME, 2012). Maximum emission standards for individual pollutants, including some odour-related, emitted from stationary sources are addressed as well (PME, 2004). The Royal Commission for Jubail and Yanbu set guideline values for compounds with the potential to cause health impact and odour annoyance, which are determined by the threshold of observable health effects on humans. Odours are addressed, therefore, by individual chemical pollutants in air (Royal Commission, 2004). The regulatory pollutants are mainly set to cover the emissions from petrochemical and energy-intensive industries. Besides, the Royal Commission Environmental Regulations report remarks that “the operator of a facility shall not emit at any time air contaminants in such concentration and of such duration as to be injurious to, adversely affect, or cause nuisance to public health or welfare, animal life, vegetation, or property”. To control emissions into the atmosphere, those responsible for the facility shall use the BAT (Royal Commission, 2004).

6.5.3. Israel

According to the Public Health Ordinance Law, from 1940, the Israel's Ministry of Environmental Protection (IMEP) and local authorities are responsible for preventing and eliminating nuisances, which may include air pollution and odours or unsanitary conditions. The Abatement of Environmental Nuisances Law (AENL) from 1961 is the key regulation in Israel for air quality, odour and noise control. According to this Law, no one may cause “any considerable or unreasonable noise or air pollution (include odours), from any source whatsoever, if it disturbs or is likely to disturb a person in the vicinity or a passerby”. The Clean Air Law provides a comprehensive framework for the air pollution reduction and prevention by assigning responsibilities and imposing obligations on the government, local authorities and industrial sector. Moreover, ambient air quality standards were first set under the AENL in 1971 and, to date, were last revised in 2008 and enacted in 2011 (IMEP, 2016). No quantitative values, however, for the determination of odour

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

exposure are established in the Clean Air Law. Consequently, Israeli authorities developed a parallel guideline, under the provisions of the AENL, to address odours (IMEP, 2013). This Guide includes the definition of a "strong odour or unreasonable", which is considered a crime according to the AENL. Therefore, maximum impact standard was set, as follows:

- 1 ou_E m^{-3} for residential areas;
- 5 ou_E m^{-3} for mixed areas;
- 10 ou_E m^{-3} for another areas.

Mixed area comprises one or more land uses designed as recreation, tourist, commercial, public buildings and light industry. Another area is the land use type that is not classified as mixed or residential. The dispersion modelling study is conducted for all odour sources together and separately, in agreement with the following scenarios:

- Existing and new facilities: simulate the maximum odour concentrations (100th percentile);
- Existing facilities: simulate the odour concentrations at the 98th percentile;
- New facilities: simulate the odour concentrations at the 99.5th percentile;

Along with Equation (4), 1-h concentrations are converted into 10-min values to simulate short-term odour peaks. The exponent n applied for this purpose is atmospheric-stability dependent. For the stability classes A and B, $n = 0.5$; stability class C, $n = 0.333$; stability class D, $n = 0.2$; stability classes E and F, $n = 0.167$. In summary, to derive the 1-h mean values to 10-min concentrations, the following F are applied: A and B = 2.45; C = 1.82; D = 1.43; E and F = 1.35. Additionally, the guide describes methods of sampling, analysis (according to EN 13725: 2003), processing of complaints, odour assessment in the field and dispersion modelling using AERMOD. Different models can be used if the relevant authority approves in advance.

7. Synthesis of odour impact criteria

Odour concentrations statistics are calculated by dispersion models and compared against a jurisdictional immission standard, the so called odour impact criteria (OIC). Basically, the OIC are limits used to define compliance. Specifically, the time series of the ambient air odour concentrations is evaluated against one or more preselected OIC shaped by three components:

i. Odour concentration threshold (C_t);
ii. Threshold percentile compliance value (P) (sometimes specified as a threshold exceedance probability);
iii. The averaging time used to calculate concentrations within the atmospheric dispersion model.

If the OIC are specified with short time intervals relating for example to human nose response time, then a peak-to-mean factor (F) is normally required to adapt the odour concentration to the typically longer averaging times used in dispersion modelling. In some jurisdictions, peak-to-mean values are effectively included in C_t values that are specified with longer term (e.g. 1-h) averaging times. The definition of specific values of C_t and P is greatly variable between jurisdictions and depends on technical and economic factors such as land use type, averaging time, industry type, offensiveness or hedonic tone of the odour and the olfactometry standard used to measure concentrations.

7.1. Odour concentration units

Most countries use units of European odour unit per hour per cubic meter (ou_E m^{-3}) to distinguish between odour concentrations determined by the European standard EN 13725:2003 and other standards. The EN 13725:2003 standard is widely used around the world as the reference method for determining the odour concentration through dynamic dilution olfactometry, whilst some jurisdictions have adopted other standards. The provinces of the Netherlands apply a unique procedure that involves the determination of the odour concentration (in ou_E m^{-3}) associated with a hedonic tone value (H), which is a relationship between suprathreshold odour concentration and the degree of (un)pleasantness. This implies that these results are expressed in ou_E(H) m^{-3} in accordance with the Dutch standard NVN 2818:2005. The U.S. adopts the unit of dilutions-to-threshold (D/T) for field assessments and ou m^{-3} for odour concentration determined under laboratory conditions using the ASTM E679-04 standard. Japan, China, South Korea, Taiwan also use D/T units derived from odour measurements using the Japanese triangular odour bag method as reference, although each country has renamed its own standard. For instance, in South Korea the determination of odour concentration is performed using the ADS test. In Denmark, the unit of LE m^{-3} is found and in the Netherlands ge m^{-3} used to be applied.

Conceptually, 1 ou_E m^{-3} can be considered equivalent to 1 ou m^{-3}, 1 ou, 1 LE m^{-3}, 1 D/T and 0.5 ge m^{-3} as these units of concentration are all determined using standards that use the concept of the odour detection threshold. However, differences in concentration may occur across these units due to differences in the standard methods used to measure this threshold (RWDI Air Inc, 2005).

Both similarities and differences can be found when comparing the odour concentration measurement standards EN 13725:2003 (Europe) and ASTM E679-04 (U.S.), for example (McGinley and Mann, 1998). The flow rate of air from the olfactometer ports to the assessors is standardized at 20 l min^{-1} within EN 13725:2003. The port should be shaped in such a way that the air velocity across its opening is at least 0.2 m s^{-1}. It is recommended that the presentation face velocity of air from the cup be kept below 0.5 m s^{-1} to avoid discomfort to the assessors. Generally, rounded glass tubes are used (mask dimension: 3–5 cm) (CEN, 2003). ASTM E679-04 recommends different values for face velocity and mask dimension. Moreover, ASTM E679-04 specifies a minimum flow rate of 3 l min^{-1}, but does not specify a maximum value. The flow rate of 20 l min^{-1} used in the European standard is therefore consistent with the American standard (Mahin, 2003). However, the different air flow rates allowed by ASTM E679-04 may lead to results in the measured odour concentrations that are not consistent with concentrations measured by EN 13725:2003.

Another difference that may occur between standards relates to the protocols used to assess the odorous air presented to assessors. Currently, methods commonly used in Europe, the U.S., Australia and New Zealand include the yes/no choice method (binary presentation) and the forced choice method (triangular presentation). Discussion continues in the scientific community regarding which is the superior method, although both are currently accepted by EN 13725:2003 and AS/NZS 4323.3:2001. Bokowa and Bokowa (2014), for example, argue that the triangular forced choice method is statistically the most accurate method. This method however has the disadvantage of taking a longer time to perform analysis than the yes/no method which increases the possibility of olfactory fatigue in assessors. Over time, this may result in less accurate concentration measurements. In some South East Asian countries such as Japan and South Korea, a method referred to as the Direct Triangular Bag Method is used (Bokowa and Bokowa, 2014). In this method, assessors sniff the bags containing different dilutions of the odour sample directly. Sample concentration is subsequently determined from the dilution ratio at which the odour can no longer be detected using human olfaction.

Differences in the order of dilutions presented to assessors may also be present amongst standards. For example, EN 13725:2003, ASTM E679-04 and AS/NZS 4323.3:2001 use an ascending or random concentration series to determine odour detection thresholds with a dynamic dilution olfactometer while the methods used in some Asian countries, such as Japan, use a descending concentration (increasing dilution) series for odour evaluations (Bokowa and Bokowa, 2014).

Differences also exist in the reference odorants used in concentration measurement standards. The Danish standard for example uses both H_2S and n-butanol as reference odorants, while the European standard EN 13725:2003 uses only n-butanol. The Japanese method requires assessors to undertake an aptitude test using five standard odorants to ensure that people selected for assessing panels do not have olfaction abnormalities.

As stated previously, primary factors of the EN 13725:2003 standard are the quality criteria for trueness and precision (repeatability). These criteria are linked to standard values of a single odorant (i.e. n-butanol). Whenever an odour laboratory meets the mandatory conditions for n-butanol, the quality level is transferable to other environmental odours (Klarenbeek et al., 2014). In the work of Klarenbeek et al. (2014), the statistical analysis of odour from 33 sources totaling 412 odour measurements, distributed in 10 proficiency tests, established that laboratories, panels and panel sessions have components of variance that significantly differ between n-butanol and other odorants ($\alpha = 0.05$). Their results do not support the transferability of the quality criteria, as determined on n-butanol, to other odorants. Klarenbeek et al. (2014) recommend the reconsideration of the present single reference odorant as laid down in EN 13725:2003.

Field olfactometers also have similarities and differences that can lead to variations in the measured odour concentration. This is the case of odour concentration determined using a nasal ranger when comparing to a Scentroid SM100, for example.

7.2. Application of odour impact criteria

The adaptation of the criteria for a given level of protection is accomplished in three ways, as follows:

i. Adjust P (frequency related to a percentile);
ii. Adjust C_t (odour concentration threshold);
iii. Adjust E (hedonic value related to the emissions).

In Germany, the C_t is assumed as a constant value, whereas the P is used to set the criteria for a certain location and offensiveness. Other countries use a constant P and modify the C_t for adjusting the criteria to the required level of protection. In this regard, Germany is the only country where the P values can be adapted depending on the hedonic tone of the odour by using the polarity profile method. Consequently, other jurisdictions adapt the C_t to the offensiveness. On the other hand, Dutch jurisdictions (e.g. North Brabant) adjust E for hedonic tone by using hedonic tone normalised emissions. The analysis of the international regulatory framework on odour criteria based on maximum impact standard approach allowed to identify basically three different groups:

i. High odour concentration thresholds combined with high percentiles (e.g. $C_t = 10$ ou; $P = 99^{th}$);
ii. Low odour concentration thresholds combined with low percentiles (e.g. $C_t = 1$ ou; $P = 90^{th}$);
iii. Low odour concentration thresholds combined with high percentiles (e.g. $C_t = 1$ ou; $P = 99^{th}$).

The first two groups were also identified by Sommer-Quabach et al. (2014). The third group can be considered the most restrictive and conservative, with use intended mainly for new installations, highly sensitive locations, intermittent emissions and most offensive odours.

In Australia, Belgium, Netherlands, U.S., Spain, Italy, Canada and Brazil the states have autonomy to develop their own odour regulations. In other countries (e.g. Chile, Colombia, Germany, Austria, France, UK, Denmark, Ireland, New Zealand, Israel) odour criteria are established under the national scope. Odours are not regulated at the level of trading blocs such as European Union. Colombia, UK, Catalonia (Spain) and Panama have similar approaches (offensiveness based) to limit offsite impacts of odours; it appears that H4 Odour Management (from UK) was used as reference to develop the criteria of these other jurisdictions. Countries such as Germany, Ireland, Belgium distinguish the criteria taking into account the offensiveness by different animal species. Other countries select the criteria depending on the desired level of protection, mostly defined by the zoning of residential areas (Sommer-Quabach et al., 2014). In this respect, there is a tendency to have the lowest C_t for residential areas and higher C_t for regions with intensive industrial and agricultural operations. Likewise, existing installations can be expected to have higher C_t, while for new facilities lower C_t. The limits embrace the different functions of the affected area, with more attention given to activities that tend to occur in a cleaner air environment (Nicell, 2009). German regulation explicitly considers background odour concentrations for impact assessments, called in GOAA (2008) the “characteristic value of the existing odour exposure”. For some situations, the Netherlands considers the cumulative effects due to clusters of odour sources as in Flanders for clusters of livestock facilities. Germany also discusses about the accumulating effect of combined odour sources. For instance, in scenarios where the lines of minimum separation distances of various adjacent livestock farms meet or overlap, or if other emission sources are nearby.

Thresholds of 0.25 ou_E m^{-3} (Germany) and 35 ou_E m^{-3} (Netherlands) and 85^{th}, 90^{th} 99.99^{th} and 100^{th} percentiles were found. In the Netherlands (provinces) limits from 0.05 to 100 $ou_E(H)$ m^{-3} are used. The *F* considered to estimate the perception of short-term impressions by the human nose also greatly varies from country to country and can assume values of 1 (i.e. without peak-to-mean assumption or embedded in the C_t hourly mean value), 10 (e.g. Queensland) and 45 (e.g. for A and B stability classes in Hong Kong). The result of such divergent *F* factors is reflected in averaging times from 1 s to 1 h. Only Austria, to our knowledge, applies a peak-to-mean concept which varies dynamically depending on both atmospheric stability and distance from the emission source. Therefore, *F* decreases with increasing distance from the source, caused by turbulent mixing. This decrease with distance effect is stronger for unstable conditions and is less pronounced for stable conditions (Piringer et al., 2015). Hong Kong, Israel and Manitoba (Canada) use *F* only depending on atmospheric turbulence (stability classes), but Manitoba for simplification and practical reasons recommends the usage of a constant factor. Therefore, this variability of odour exposure limits demonstrates the lack of harmonisation among jurisdictions for the selection of odour impact criteria (maximum impact standard), without even mentioning other types of criteria. According to Griffiths (2014), this lack of agreement constitutes a noteworthy gap in best-practice standards for odour impact assessment methodology and creates a considerable risk of poor odour impact studies outcomes.

Consistent with the review presented in this work and to our knowledge, the exposure limits used in Denmark and Norway are the only ones to apply a monthly percentile. All other jurisdictions apply percentile values on an annual basis. In the latter case, some regulations are not clear if the criterion is applied for individual years or over the set of meteorological years requested. This is a very serious issue as inter-annual variability in meteorology can lead to different impact patterns. Moreover, for dispersion modelling studies conditioned to permits, some regulations set 1 year as a minimum of meteorology (e.g. Manitoba) to perform the simulation while others require 10 years of weather data (e.g. Netherlands). The utilization of the BAT is required by most jurisdictions, especially in the European Union and North America, as a mandatory prerequisite for acquisition of environmental permits regardless of compliance with odour criteria.

Another area of difference in OICs relates to the number of percentile thresholds applied. Most jurisdictions use the single percentile concept. However, some jurisdictions (e.g. New Zealand, Quebec, City of Boucherville, Austria and historically Western Australia utilize a multi-percentile concept. Griffiths (2014) shows that a multi-percentile criterion is conceptually better suited to capturing the influence of both the frequency and intensity dimensions of nuisance odour than a single percentile criterion. A well designed and calibrated multi-percentile criterion framework should in principle have better skill in predicting odour nuisance incurred by both acute and chronic odour exposure conditions and variations of these conditions. Furthermore, some jurisdictions recommend that the odour impact is assessed using a risk matrix (e.g. state of Victoria – broiler farms, Norway – KVALUR method). These examples use the multi-percentile concept to delineate zones of different impact risk.

7.3. Summary of OIC

A selection of impact criteria used in international jurisdictions to regulate odour is summarized in Table 3. Some of the criteria may have been revoked or will be updated in the near future. Current information about the odour impact criteria (OIC) detailed in Table 3 can be found in Section 6. As discussed, special emphasis was placed on investigating and comparing immission limits based on time series of odour concentration calculated by atmospheric dispersion models. Indeed, the comparison of model-predicted odour concentration statistics against OIC is identified as one of the most common tools used by regulators to evaluate the risk of odour impacts at sensitive receptor locations in planning stage odour impact assessments and is also used to inform assessment of odour impacts of existing facilities. This type of criterion is defined as maximum impact standard approach and provides immission protection.

8. Summary of regulatory approaches and critical discussion

To provide a comprehensive collection of regulatory approaches and deliver a critical thinking and recommendations of the subject, the following topics with questions and answers are presented.

8.1. Why has odour regulation proved so challenging to establish and match with community expectations?

The primary goal of odour regulatory frameworks is to limit odour exposure in the community to levels that protect amenity in both the short and long term, thus avoiding complaints. However, as noted in EA (2002) the processes leading from odour formation to annoyance and loss of amenity in the community are complex and depend on many factors that affect both perception and appraisal of odour.

The processes that start with the emission of odour from a source and end in complaints are summarized by Pullen and Vawda (2007) as:

- Estimation of odour release value;
- Dispersion modelling to estimate the odour exposure;
- Correlation of the predicted exposure against the expected degree of annoyance, and;
- Correlation with negative coping behaviours (nuisance and complaint).

Factors that contribute to difficulties in establishing robust predictive tools for assessments of proposed works arise at all stages of this source – pathway – receptor model of impact and include the following challenging areas.

8.1.1. Difficulties in estimating odour emission rates

Reliable characterization of emissions for input into dispersion models is crucial for robust calibration of exposure criteria against metrics of annoyance such as complaints. Such measurements can be difficult to obtain, however, due to:

- Difficulty in establishing concentration and flow-rates for the often fugitive or diffuse nature of emissions;
- Difficulty in characterising temporal variations in emissions due to process variations and weather;
- Significant variability in results depending on equipment used for sampling for some source types such as area sources;
- The lack of equipment available for accurately monitoring odour emissions in real time;
- The significant levels of uncertainty in the concentration measurement process via dynamic olfactometry.

These difficulties are perhaps even more pronounced for planning stage assessments as measurements are not able to be undertaken and exact details of the technology used, process conditions, throughput and management practices are often not available. In such cases the use of conservative emissions models may be warranted.

8.1.2. Uncertainties in dispersion modelling

Difficulties in accurately predicting odour exposure via dispersion modelling also occur due to uncertainties in the modelling process. These can occur due to:

- Different methods used to generate meteorology, including the use of observations and prognostic meteorological models;
- Difficulties in some models in handling particular meteorological conditions such as light-wind calms;
- Sensitivity of model output to model settings;
- Differences in the physics assumed by regulatory models;
- Differences in the treatment of peak-to-mean considerations for odour modelling.

The uncertainties associated with odour modelling are treated in depth by Pullen and Vawda (2007). These authors noted that new generation models can vary by up to a factor of 8 in output for high percentile calculations with significant wake effects.

8.1.3. Correlating exposure to annoyance

Calibration of OICs for predictive modelling depends upon linking exposure to annoyance and complaints. However, perhaps the largest difference noted in this review in predictive assessment tools used by jurisdictions relates to the threshold and percentiles of OICs used for dispersion modelling assessments for this purpose.

OICs – in the simplest form – only addresses the Frequency and Intensity dimensions of FIDOL, via the percentile and threshold parameters. As noted by Griffiths (2014) single percentile criteria in common use by jurisdictions may have significant shortcomings in ability to align well with even these two FIDOL dimensions, with a multi-percentile concept suggested as a way of mitigating these shortcomings.

The hedonic tone (offensiveness) FIDOL dimension is accommodated in OICs by some jurisdictions by applying adjustments to the threshold parameter or emissions (the Netherlands).

Similarly, receptor sensitivity adjustments for the Location dimension of FIDOL are included by some jurisdictions. However, the addition of these parameters adds further complexity to attempts to robustly calibrate criteria via dose-response studies.

As noted by EA (2002), individual responses to odour exposure are highly personal and subjective in nature and factors influencing responses extend beyond the simple FIDOL dimensions of nuisance odour. Appraisal of a particular exposure event may, for example, be influenced by factors such as:

- Personal history of exposure to the same or similar odorants;
- Personal connection with the facility responsible for the odour source;
- Olfactory memories;
- The psychological impressions of events associated with those exposure events,
- Mood;
- Personal coping strategy, and
- Physical attributes including age, health, gender and genetics.

No valid model to comprise these and other factors and predict annoyance is currently available. Even if such a model existed, considering the number of variables involved, it would be questionable whether such an analytical prediction of the annoyance would indeed be feasible and valid. Therefore, dose-response relationships, established through real case studies, aim to establish the link between the percentage of people annoyed and calculated exposure to odours (Hobson and Yang, 2014).

8.1.4. Net effect of factors

The factors described above have contributed to the challenges for regulators to establish clear causal links between emissions at source, exposure and nuisance leading to complaints. These factors have, in the view of the authors, contributed to the significant diversity present in jurisdictional OICs used for predictive dispersion modelling and also other aspects of odour regulation. Many of these factors relate to properties inherent to odour and are not present for classical air pollutants such as particulates or hydrogen sulphide.

8.2. How have different regulatory regimes drawn evidence from communities, regulators and other countries to determine acceptable limits?

A variety of approaches have been used by jurisdictions in setting regulatory odour limits. Dose-response studies correlating model-predicted exposure statistics to population response for example have traditionally provided a desirable means of calibrating modelling OICs for a given level of protection (e.g. Miedema et al. (2000)). Exposure limits in countries as Netherlands, Germany, UK were determined in this fashion. However as demonstrated in this review, OICs in current use are often based upon a single concentration percentile and a consensus as to which percentile value optimally delineates nuisance odour boundaries has yet to be reached. This has posed a significant problem for researchers undertaking dose-response studies and has contributed to a diversity of OICs that can calculate significantly different distances for similar levels of protection (van Belois and Both, 2004; Schauberger and Piringer, 2012; Griffiths, 2014).

In some jurisdictions, logical considerations are used to set OIC values. The Australian state of Queensland for example notes that the 99.5th percentile value used in its criterion is a statistical parameter that filters out extreme values (EHP, 2013). The accompanying threshold value of 5 ou with a nose-response averaging time is selected on the basis that this level of odour can cause general annoyance. This threshold is subsequently converted to hourly averaged concentrations of 2.5 ou for ground-level sources and wake-affected stacks and 0.5 ou for wake-free stacks on the basis of peak-to-mean arguments.

Health based exposure limits are sometimes used for single chemical species (e.g. NSW) where these are more conservative than the amenity based limits. As noted elsewhere in this document such limits are also applied to determine appropriate stack emission limits in some jurisdictions (e.g. NSW).

Correlation of immissions data collected via field observations with empirical indicators of nuisance is desirable but is difficult to undertake due to the resources and time periods required to obtain the necessary data. Difficulties also exist in determining the precise manner in which the several dimensions of collected immissions data (e.g. frequency, intensity, hedonic tone) relate to nuisance effects. However, in a study spanning a number of years, immission limits for ambient air in Germany were determined by comparing odour field data collected by panelists with community responses (Sucker et al., 2008a, 2008b). Unusually for a jurisdiction, these limits also provided the basis for the percentile and threshold values in German OICs for modelling (Janicke et al., 2004) and direction-dependent separation distance equations for intensive livestock operations (Schauberger et al., 2012b).

8.3. Summary of approaches used by jurisdictions

The categorisation of the five main approaches used to assess odour impacts within the odour regulations reviewed in this work is presented in Table 4. When a jurisdiction appears in two or more places, that is because this jurisdiction uses more than one approach to assess odour impacts. Therefore, the categories are not mutually exclusive so one jurisdiction can use different tools for different situations. Table 4 is not intended to provide the complete categorization of all approaches used by the jurisdictions but examples of how the categorization is addressed.

Currently, another issue facing policy makers is the heterogeneity of regulatory approaches due to different lines of thoughts adopted, as shown in Table 4. Despite the difficulties and complexities involved in the field of environmental odours, besides the asymmetry and lack of harmonisation between the jurisdictional odour impact criteria, standardized methods of sampling, analysis and impact assessment combined with scientifically supported and well-defined objective and quantitative exposure criteria, along with the use of BAT and the application of FIDOL principles, can build a consistent basis for setting harmonious regulatory approaches. These endeavours can make implementing odour regulations increasingly affordable.

Furthermore, relevant authorities and regulators should be committed to the cause to establish public policies. Regulatory processes, generally, are time consuming and must go through a review process and extensive discussion. Accordingly, this work is an opportunity to narrow the methodological gap between the actual regulations and make this complicated process more tangible and accessible. Consequently, the establishment of regulations to adequately protect citizens can be accessed more readily.

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160

Table 4
Examples of jurisdictions that uses one or more of the five approaches to assess odour impacts.

Approach	Description	Jurisdiction
Maximum impact standard	Odour	Canadian jurisdictions, Chile, Colombia, U.S. jurisdictions, Panama, Paraná (Brazil), UK, Germany, Austria, Lombardy (Italy), Puglia (Italy), Ireland, Netherlands, Israel, Taiwan, Hong Kong, South Korea, China, Japan, Australian jurisdictions, Hungary, Belgian jurisdictions, Catalonia (Spain), Denmark, Belgian jurisdictions, France, Austria
	Odour-related individual chemicals	Canadian jurisdictions, Colombia, U.S. jurisdictions, São Paulo (Brazil), Panama, South Korea, Japan, Australian jurisdictions, Australian jurisdictions, Denmark, Puglia (Italy)
Separation distance standard	Variable	U.S. jurisdictions, Paraná (Brazil), Austria, Netherlands, Australian jurisdictions, Belgian jurisdictions, Denmark, Belgian jurisdictions, Canadian jurisdictions, Austria, Germany
	Fixed	Canadian jurisdictions, U.S. jurisdictions, Netherlands, Hong Kong, Australian jurisdictions, Germany
Maximum emission standard	Odour	France, Italian jurisdictions, China, Australian jurisdictions, Denmark
	Odour-related individual chemicals	Chile, Panama, Brazil (federal), Puglia (Italy), China, Japan, Australian jurisdictions
Maximum annoyance standard	Number of complaints	U.S. jurisdictions, Wellington (New Zealand)
	Annoyance level	New Zealand
Technology standard	BAT	European countries, Canadian jurisdictions, U.S. jurisdictions, Australian jurisdictions, New Zealand, Saudi Arabia, Colombia

Although, within conventional air pollutants, which is a more evolved field when comparing to odours, constant progress is observed. Additionally, even more people desire a progressively healthy environment demanding more stringent air quality standards every day. Thus, the challenge is also continuous within the odour field and need to be faced day after day.

In summary, this work supports that of other researchers in concluding that numerous areas require additional research to improve standardisation and harmonisation of odour impact criteria or limits across jurisdictions (van Belois and Both, 2004; Piringer et al., 2016a).

8.4. *Integrated multi-tool strategy for odour assessment*

The regulation of environmental odour proved to be a complex and challenging matter to face for several reasons, as the strict connection with human appraisal. The human response to odours is essentially subjective in nature. The appraisal is influenced by many factors as previously described (e.g. emotion, olfactory memories, individual sensorial perception, gender). Besides, a diversity of approaches to asses and manage odour impacts to avoid nuisance are used under the international regulatory framework.

Unlike noise, there are no “simple” instruments which can be used to accurately measure odours in the field. Practitioners should try, however, to evaluate actual and potential odour impacts in an objective and impartial way. Thus, that will be fair and reasonable to both site operators and sensitive receptors (DEFRA, 2010). When comparing odours with conventional air quality pollutants, conventional pollutants are often assessed using a single tool. Nevertheless, the preference towards combining different tools for odour assessments is also an aspect that distinguishes this type of pollutant from the others (Bull et al., 2014). Currently, successful legislations use a combination of approaches with different tools and methods to address odour issues. In this work, the recommended integrated multi-tool strategy for odour assessment studies are encompassed into three categories (adapted from Bull et al. (2014)):

Predictive:

- Qualitative: risk-based assessments using Source-Pathway-Receptor concept;
- Semi-quantitative: screening models, look-up tables and nomographs;
- Modelling: atmospheric dispersion models.

Observational/Empirical:

- Monitoring of odour in ambient air: sensory (e.g. field panel sniff testing, field olfactometry), chemical compound analysis (e.g. H_2S, NH_3, VOCs), and sense-instrumental methods (e.g. electronic noses);
- Human panels: plume and grid methods using assessors;
- Actively using the community as the sensor: odour diaries and community surveys;
- Passively using the community as the sensor: complaints analysis.

Mitigation/Control:

- Minimize and control odour impact risks: BAT, management plans, proactive measures, source emission limits.

We concur with previous assessment framework reviews (e.g. (RWDI Air Inc (2005); DEFRA (2010); Bull et al. (2014)) that relevant elements of assessment frameworks are:

1. Impact assessment of new proposals: predictive tools such as OIC modelling and fixed and variable separation distance equations are amongst the few useful tools available for assessment of new “green-fields” proposals or expansions of existing sites;
2. Impact assessment of existing facilities: observational and empirical data tools indicating if an odour issue is present from an existing site such as complaints analysis, community surveys and odour field studies such as plume and grid methods;
3. Mitigation and control plans: tools to assist industry to minimize and manage odour impact risks once proposed facilities become operational: BAT, source emission limits and robust proactive odour management plans.

Impact assessment of new proposals and impact assessment of existing facilities are the groups that fits the scenarios practitioners will need to consider in most situations. Although, practitioners can also face scenarios that will need to contemplate risk mitigation plans. In comprehensive or complex situations, the three scenarios can be addressed.

As listed, Category 1 tools aren't the best for category 2, and Category 2 tools are not available to be used for new proposals like Category 1 tools – they are quite distinct in purpose. Neither Category 1 or 2 tools can assist Category 3 goals. Therefore, a diversity of tools is not necessary a sign of non-optimum regulatory framework. In fact, it can be the opposite and be indicative of a mature and effective framework.

Therefore, where feasible, as a best practice measure, its recommended to use multiple methods and tools under an integrated strategy. Different assessment methods and tools are not mutually exclusive, opportunely. Using them in combination individual limitations can be minimized and, consequently, increase confidence in the overall conclusion (Bull et al., 2014). Assessments are certainly stronger when multiple lines of convergent evidence support each other. For instance, field inspection data supports complaints data which are inside calculated separation distances, and poor levels of technology are present at the industry. This humble example demonstrates that an integrated strategy consisting of multi-tools is much stronger than any individual tool by itself. Another example described by Bull et al. (2014) shows that the assessment of the impact on a proposed development land around an existing odour source could be conducted, as follows:

i. Monitoring (e.g. field panel sniff tests or field olfactometry) can provide a measure of odour at specific receptors under the conditions prevailing at the periods of the sampling, but cannot cover all receptor locations under every meteorological condition over a typical year;
ii. Complementing monitoring with dispersion modelling provides greater spatial and temporal coverage and the reasonableness of the estimates from the model can be compared with the observed (i.e. monitored) levels;
iii. Modelling (and probably monitoring) is only likely to characterize normal operations of the odour source, whereas it is known that unexpected events (e.g. breakdowns) and abnormal operations at some facilities can account for a significant proportion of high odour episodes. If there are already receptors in the locality, analysis of historical complaints data can provide an alternative perspective on the impact that is inclusive of such unexpected events and abnormal operations.

Moreover, measurements of odour in ambient air for impact assessment using analytical instruments or field olfactometers are not yet indicated due to many reasons (e.g. space-time representativeness, lack of standardized methods). However, odour measurement in ambient air are already useful to confirm the occurrence of a significant impact at a receptor and for monitoring emissions, for example. To assess odour impacts from recognizable odours in the field through odour measurements, VDI 3940 German grid method, which makes use of a panel (human nose working as the “sensor”), would be better indicated nowadays. Recently, the use of field olfactometers in conjunction with the VDI 3940 has also been investigated.

For impact assessment purposes a disuse of intensity scales was observed in the regulations, apart from the Australian state of Queensland, although they are still used for other goals. Maximum odour emission standards are also not being widely applied as impact assessment tools in recent regulations, especially for new developments, but in some cases, it can be used as an emission control mechanism. On the other hand, maximum emission standards for individual chemical compounds are still largely applied for emissions control. Specifically, about odour criteria, currently there is a tendency to set impact criteria in ambient air (immission protection) in terms of odour concentration threshold and a probability of exceedance of this threshold (percentile), associated or not with a peak-to-mean factor. The use of OIC modelling is a more robust method when compared to pre-established fixed or variable (equation based) distances. In cases where dispersion modelling is not applicable, field assessments to determine exposure levels are useful tools, in addition, because these methods consider the real odour perception in situ.

The combination of sensorial and analytical methods to characterize odorous gases in terms of its concentration (C), intensity (I), character (C), offensiveness (O), and persistency (P) are also highlighted through the use of the CICOP dimensions. Therefore, when these techniques are combined, odours can be better described in terms of perceived effects and chemical composition.

In this review, it is noted that FIDOL factors or dimensions of nuisance odour provide some guidance as to considerations that might be included when undertaking OIC modelling to predict nuisance odour impact extents. These include criterion adjustment for hedonic tone (O), receptor sensitivity (L), peak-to-mean (I). Additionally, a well calibrated multi-percentile criterion framework appears to offer greater alignment with the F and I dimensions of FIDOL potentially offering better predictive skill than single percentile criteria by capturing the influence of both chronic and acute impact events.

For existing facilities, all the FIDOL factors have been triggered if (verified and confirmed) complaints occur. FIDOL are not relevant for risk mitigation strategies, thus best practices measure as emissions control technology and odour management plans are mode indicated. Plume studies (e.g. VDI 3940 part 2) might be used to get previous information of the extent of odour footprint or identify the source (however, as the limitation this method doesn't define limits). The Department of Environment Regulation from Western Australia has used plume studies very effectively to track plumes kilometers away and unambiguously identify sources and characterize distinct odour footprint extents.

Therefore, the benefits generated by a comprehensive assessment under an integrated multi-tool strategy are evident when compared to individual methods. Each tool has its own strengths, limitations, and preferred applications (Bull et al., 2014; Brattoli et al., 2015). The details and examples of how to select the appropriate method for a particular situation is provided in Bull et al. (2014).

Based on previous experiences and the understanding of which methods and tools might be successfully applied, the previous recommendations for an integrated strategy to odour assessments are delivered. Naturally, adaptations to local and potentially unique contexts are preferable. Therefore, a tailor-made multi-tool integrated strategy is recommended, among other aspects, to adequately protect communities from olfactory nuisances and develop harmonized policies to prevent and control odour impacts.

We can also resume additional procedures, methods and tools that still needs improvements to make odour impact assessments more consistent:

- Inter-annual variability in meteorology for dispersion modelling studies;
- Odour concentration sample degradation: time elapsed between collection of odour samples and olfactometric analysis;
- Some bag materials are more indicated than others to store specific odorants;
- Suggest FIDOL as predictive tool basis and align each predictive tool with FIDOL letter if possible;
- Multi-percentile concept better aligns with F and I; However, still no agreed values for multi-percentile thresholds;
- Use of multiple odorants in olfactometry for a standard improvement;
- Better and more dose-response studies are strongly needed;
- Easy and conservative screening step not always present in jurisdictions;
- Standardized standards for complaint analysis;
- Still questions about best model averaging time (peak-to-mean factors);

- Constant update on progress of new and revised useful standards.

9. Conclusion

The odour policy in 28 selected countries over America, Europe, Oceania, Asia, Africa and Middle East was reviewed to address the criteria employed according to the desired level of protection. This enabled the identification and categorization of five main approaches (i.e. maximum impact standard, separation distance standard, maximum emission standard, maximum annoyance standard, technology standard) used within the jurisdictions, besides the principles of Nuisance Law. The most commonly approach towards the assessment of odour impact risks is the maximum impact standard with the application of odour concentration limits in ambient air, which are set by the odour impact criteria *OIC*. Odour concentration thresholds, percentiles and peak-to-mean factors comprise a wide range of values. The definition of the OIC, therefore, is highly variable among jurisdictions and depends on several factors demonstrating the currently lack of harmonisation. Guidelines developed for impact assessment are not designed to satisfy zero odour, but rather to minimize the nuisance effect to acceptable levels to a variety of sensitive receptors in the surrounding region of the odour sources. Furthermore, we showed why odour regulation has proved so challenging to establish and match with community expectations and how regulatory regimes have drawn evidence from communities, regulators and other countries to determine acceptable limits of odour in ambient air. The benefits of an integrated multi-tool strategy for impact assessment of new proposals, existing facilities and mitigation and control plans are demonstrated when compared to individual methods. The reactive and proactive tools and methods to form an integrated strategy are encompassed into predictive, observational/empirical and mitigation/control. The implementation of clear and objective odour regulations based on an integrated strategy is the key to the long-term success of management of environmental odours. This is supported by consolidated practical and scientific expertise. There is also a positive social impact, given that odours affect the quality of citizens' lives and can promote the depreciation of property values in exposed communities. An integrated multi-tool strategy for odour assessment should be considered in the light of the environmental and spatial planning policy as well. Moreover, this work can assist the improvement of the regulations currently in force and the development of new regulations in jurisdictions that still do not have instruments to legislate on the field of environmental odour. With the appropriate mechanisms, relevant authorities and industry can act solidly to avoid or solve conflicts, besides providing information to the public about the desired level of protection. However, additional research to improve standardisation and harmonisation of odour exposure limits across jurisdictions are still needed.

Acknowledgments

The authors gratefully acknowledge financial support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) in the form of scholarship for the first author. We also would like to thank very much Günther Schauberger (Austria), David Giard (Canada), EPD staff (Hong Kong), Rommel Molod and Don Labossiere (Canada), François-Xavier Philippe, Jacques Nicolas and Gunther Van Broeck (Belgium), EPA staff (Taiwan), Ki-Hyun Kim (South Korea), Anna Bokowa (Canada), Melinda Nyitrai-Cseh (Hungary), Selena Sironi (Italy), Per Løfstrøm (Denmark) and Karina Ødegård and Elisabeth Møyland (Norway) for the assistance with the regulations of your jurisdiction.

References

ADEME, 2005. Pollutions Olfactives: Origine, Législation, Analyse, Traitement. Agence de l'environnement et de la maîtrise de l'énergie, Dunod, Paris.
AFNOR, 1993. Association Française de Normalisation. NF X 43–103: Qualité de l'air – Mesurage de l'odeur d'une Atmosphère gazeuse – Méthode supraliminaire. AFNOR, La Défense.
Arpa Puglia, 2014. Linee guida per il rilascio di pareri riguardanti le emissioni in atmosfera prodotte dagli impianti di depurazione. Agenzia regionale per la prevenzione e la protezione dell'ambiente. Rev_0 del 17/12/2014.
AS/NZS, 2001. Australian and New Zealand Standards. AS/NZS 4323.3:2001 Stationary Source Emissions - Determination of Odour Concentration by Dynamic Olfactometry. AS/NZS, Sydney.
ASTM, 2010. American Society for Testing and Materials. ASTM E544–10: Standard Practices for Referencing Suprathreshold Odor Intensity. ASTM, West Conshohocken.
ASTM, 2011. American Society for Testing and Materials. ASTM E679–04. Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. ASTM, West Conshohocken.
Baumann, R., Brandstätter, M., Heimburger, G., Kranabetter, A., Moshammer, H., Oitzl, S., Rau, G., Schauberger, G., Schauer, U., Scheicher, E., Schopper, A., Weber, A., Wieger, G., 2013. Richtlinie zur Erfassung und Bewertung der Luftqualität in Kurorten. Medieninhaberin und Herausgeberin: Österreichische Akademie der Wissenschaften. Kommission für Klima und Luftqualität, Wien, p. 63.
Beychock, M.R., 1994. Fundamentals of Stack Gas Dispersion, 3 ed. M.R. Beychock, Ervine.
Bilsen, I., De Fré, R., Bosmans, S., 2008. Code Van Goede Praktijk Bepalen Van De Geurverspreiding Door Middel Van Snuffelploegmetingen - 2008/MIM/R/022. Departement Leefmilieu, Natuur en Energie (LNE), p. 25.
Bockreis, A., Steinberg, I., 2005. Measurement of odour with focus on sampling techniques. Waste Manag. Oxf. 25, 859–863.
Bokowa, A., Bokowa, F., 2014. Comparing the accuracy of three odour analysis techniques used in Europe, North America, Australia, New Zealand and Asia. Chem. Eng. Trans. 40, 1–6.
Boucherville, 2008. Règlement Numéro 2008-109. Règlement Relatif Aux Nuisances Olfactives. Boucherville.
Brancher, M., De Melo Lisboa, H., 2014. Odour impact assessment by community survey. Chem. Eng. Trans. 40, 139–144.
Brancher, M., Schauberger, G., Franco, D., De Melo Lisboa, H., 2016. Odour impact criteria in South American regulations. Chem. Eng. Trans. 54, 169–174.
Brasil, 1975. Decreto Nº 76.389, de 3 de outubro de 1975: Dispõe sobre as medidas de prevenção e controle da poluição industrial, de que trata o Decreto-lei nº 1.413, de 14 de agosto de 1975, e dá outras providências. Diário Oficial da União, Brasília, DF, Poder Executivo, Seção 1, 06 out, p. 13329.
Brasil, 1981. Lei nº 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional de Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, v. 119, Fasc. 167, 02 set. 1981, Seção I, pp. 16509–16512.
Brattoli, M., Mazzone, A., Gennaro, G., Giua, R., Blonda, M., Assennato, G., 2015. A methodological approach for the development of an odour regulation in Puglia Region (Italy). In: Proceedings of the Odour Management Conference & Technology Showcase (OMCTS). Scentroid, Toronto, ON.
Bull, M., McIntyre, A., Hall, D., Allison, G., Redmore, J., Pullen, J., Caird, L., Stoaling, M., Fain, R., 2014. Guidance on the Assessment of Odour for Planning. Institute of Air Quality Management (IAQM), London.
Capelli, L., Sironi, S., Del Rosso, R., Céntola, P., Il Grande, M., 2008. A comparative and critical evaluation of odour assessment methods on a landfill site. Atmos. Environ. 42, 7050–7058.
Capelli, L., Sironi, S., Del Rosso, R., Guillot, J.-M., 2013. Measuring odours in the environment vs. dispersion modelling: a review. Atmos. Environ. 79, 731–743.
CASANZ, 2013. The clean air society of Australia and New Zealand. In: Agapides, N. (Ed.), Air Quality Regulations and Odour Management in Australia and New Zealand. Legislative and Policy Frameworks, New South Wales, p. 70.
CEN, 2003. European Committee for Standardization. EN 13725: Air Quality: Determination of Odour Concentration by Dynamic Olfactometry. CEN, Brussels.
CETESB, 2014. Manual para Elaboração de Estudos para o Licenciamento com Avaliação de Impacto Ambiental. Companhia Ambiental Do Estado De São Paulo. Available at: http://licenciamento.cetesb.sp.gov.br/. Acessed in 05 May 2015.
Chen, S.-J., Hsieh, L.-T., Hwang, W.-I., Xu, H.-C., Kao, J.-H., 2003. Abatement of odor emissions from landfills using natural effective microorganism enzyme. Aerosol Air Qual. Res. 3, 87–99.
Cimorelli, A., Perry, S., Venkatram, A., Weil, J., Paine, R., Wilson, R., Lee, R., Peters, W., Brode, R., Paumier, J., 2004. AERMOD: Description of Model Formulation. US Environmental Protection Agency, North Carolina, p. 91.
Cimorelli, A.J., Perry, S.G., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, R.B., Lee, R.F., Peters, W.D., Brode, R.W., 2005. AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. J. Appl. Meteorol. 44, 682–693.
CIWEM, 2012. Chartered Institution of Water and Environmental Management. Policy Position Statement. Control of Odour, p. 8. Available at: www.ciwem.org. Acess in 05 May 2016, London.

CNIC, 2007. Centro Nacional de Información de la Calidad. Contaminación Odorífera, p. 5. Available at: http://www.aec.es/. Acessed in 29 April 2016, España.
Colls, J., Tiwary, A., 2010. Air Pollution: Measurement, Modelling and Mitigation, 3 ed. Routledge, New York.
CONAMA, 1990. Resolução CONAMA nº 3, de 28 de junho de 1990: Dispõe sobre padrões de qualidade do ar, previstos no PRONAR. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 22 ago. 1990, Seção 1. Conselho Nacional do Meio Ambiente, pp. 15937–15939.
CONAMA, 2011. Resolução CONAMA nº 436, de 22 de dezembro de 2011: Estabelece os limites máximos de emissão de poluentes atmosféricos para fontes fixas instaladas ou com pedido de licença de instalação anteriores a 02 de janeiro de 2007. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 26 dez. Conselho Nacional do Meio Ambiente, pp. 304–311. Complementa as Resoluções nº 05, de 1989 e nº 382, de 2006.
Cseh, M., Nárai, K.F., Barcs, E., Szepesi, D.B., Szepesi, D.J., Dicke, J.L., 2010. Odor setback distance calculations around animal farms and solid waste landfills. Q. J. Hung. Meteorol. Serv. 114, 303–318.
CUM, 2001. Communauté Urbaine de Montréal. Règlement no 90 de la C.U.M., modifié par les Règlements nos 90-1, 90–2 et 90-3. Règlement relatif à l'assainissement de l'air. CUM, Quebec.
DAFF, 2012. Queensland Guidelines Meat Chicken Farms. Department of Agriculture, Fisheries and Forestry, p. 56.
De Melo Lisboa, H., Guillot, J.-M., Fanlo, J.-L., Le Cloirec, P., 2006. Dispersion of odorous gases in the atmosphere — Part I: modeling approaches to the phenomenon. Sci. Total Environ. 361, 220–228.
De Melo Lisboa, H., Sivret, E.C., Stuetz, R.M., 2014. Odour regulations – experiences from Australia. Chem. Eng. Trans. 40, 181–186.
DEC, 2005. Department of Environment and Conservation. Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales. Department of Environment and Conservation, Sydney, p. 63.
DEC, 2006a. Department of Environment and Conservation. Technical Framework: Assessment and Management of Odour from Stationary Sources in NSW. Air Policy Section of the Department of Environment and Conservation. Department of Environment and Conservation, Sydney, p. 62.
DEC, 2006b. Department of Environment and Conservation. Technical Notes: Assessment and Management of Odour from Stationary Sources in NSW. Department of Environment and Conservation, Sydney, p. 68.
DEC, 2007. Department of Environment and Conservation. Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales. Department of Environment and Conservation, Sydney, p. 37.
DEFRA, 2009. In: Parker, C., Gibson, N. (Eds.), Department for Environment, Food and Rural Affairs. Good Practice and Regulatory Guidance on Composting and Odour Control for Local Authorities. DEFRA, London, p. 87.
DEFRA, 2010. Department for Environment, Food and Rural Affairs. Odour Guidance for Local Authorities. DEFRA, London, p. 110.
DEP, 2002. Western Australian Department of Environmental Protection. Odour Methodology Guideline. DEP, Perth, p. 28.
DEPA, 2002a. Guidelines for Air Emission Regulation. Limitation of Air Pollution from Installations - Environmental Guidelines Nr. 1. Danish Environmental Protection Agency, Denmark, p. 117.
DEPA, 2002b. Industrial Odour Control - Environmental Guidelines No. 9. Danish Environmental Protection Agency, Denmark, p. 28.
DEPA, 2009. Order Amending the Order on Permits and Approvals Etc. For Livestock Farms. Order No 294 of 31 March 2009. Danish Environmental Protection Agency.
DER, 2015. Department of Environment Regulation. Guidance Statement: Separation Distances - Division 3, Part V, Environmental Protection Act 1986. DER, Perth, p. 16.
DMAV, 2005. (Departamento de Medio Ambiente y Vivienda). Dirección General de Calidad Ambiental. Generalidad de Cataluña. Borrador del anteproyecto de ley contra la contaminación odorífera. DMAV, Barcelona, p. 26.
Drew, G.H., Smith, R., Gerard, V., Burge, C., Lowe, M., Kinnersley, R., Sneath, R., Longhurst, P.J., 2007. Appropriateness of selecting different averaging times for modelling chronic and acute exposure to environmental odours. Atmos. Environ. 41, 2870–2880.
EA, 2002. Environment Agency. Assessment of Community Response to Odorous Emissions. R&D Technical Report P4-095/TR. EA, Bristol, p. 125.
EA, 2010. Environment Agency. Odour Management Plans for Waste Handling Facilities. Version 1.0. EA, Bristol, p. 11.
EA, 2011. Environment Agency. Additional Guidance for H4 Odor Management: How to Comply with Your Environmental Permit. EA, Bristol, p. 43.
EHP, 2013. Queensland Department of Environment and Heritage Protection. Guideline: Odour Impact Assessment from Developments. EHP, Brisbane, p. 27.
EPA Ireland, 2001. Odour Impacts and Odour Emission Control Measures for Intensive Agriculture. R&D Report Series No. 14. Environmental Protection Agency, Wexford, Ireland, p. 104.
EPA Ireland, 2010a. Air Dispersion Modelling from Industrial Installations Guidance Note (AG4). Environmental Protection Agency, Wexford, Ireland, p. 76.
EPA Ireland, 2010b. Odour Impact Assessment Guidance for EPA Licensed Sites (AG5). Environmental Protection Agency, Wexford, Ireland, p. 17.
EPA Tasmania, 2004. Environment Protection Policy (Air Quality) 2004. Environment Division, Department of Tourism, Arts and the Environment, Hobart: Department of Primary Industries, Water and Environment. Tasmania Environment Protection Authority, p. 21.
EPA Tasmania, 2014. Tasmania Environment Protection Authority. Tasmanian Atmospheric Dispersion Modelling Guidelines. V 0.93d (Draft). EPA Tasmania, Hobart, p. 5.
EPA Victoria, 2001. State Environment Protection Policy (Air Quality Management). Environment Protection Act 1970. Victoria Government Gazette. No. S 240 Friday 21 December 2001. Environmental Protection Authority of Victoria, Melbourne, p. 52.
EPA Victoria, 2012. Environmental Protection Authority of Victoria. Broiler Farm Odour Environmental Risk Assessment. Publication 1509. EPA Victoria, Carlton, p. 6.
EPA Victoria, 2013a. Environmental Protection Authority of Victoria. Construction of Input Meteorological Data Files for EPA Victoria's Regulatory Air Pollution Model (AERMOD). Publication 1550. EPA Victoria, Carlton, p. 17.
EPA Victoria, 2013b. Environmental Protection Authority of Victoria. Guidance Notes for Using the Regulatory Air Pollution Model AERMOD in Victoria. Publication 1551. EPA Victoria, Carlton, p. 3.
EPA Victoria, 2013c. Environmental Protection Authority of Victoria. Recommended Separation Distances for Industrial Residual Air Emissions. Publication 1518. EPA Victoria, Carlton, p. 17.
EPD, 2011. Environmental Protection Department. Environmental Impact Assessment Ordinance - Technical Memorandum. Annex 4: Criteria for Evaluating Air Quality Impact and Hazard to Life of the Technical. Available at: http://www.epd.gov.hk/. Acessed in 10 May 2016.
EPD, 2016. Environmental Protection Department. Guidelines on Choice of Models and Model Parameters. Available at: http://www.epd.gov.hk/. Acessed in 11 May 2016.
Epstein, E., Freeman, B.C.S., 2004. Legal and Regulatory Aspects Related to Odors. Proceedings of the WEF/A&WMA Odors and Air Emissions. Water Environment Federation, Bellevue, WA.
ERM, 2012. Environmental Resources Management. Broiler Farm Odour Environmental Risk Assessment - Background to Technical Guidance. Environmental Protection Authority of Victoria, Docklands: ERM, Reference: 0164677, p. 65.
Ferguson, J., Tebbutt, S., 2015. International Regulatory Approaches for Odour. Proceedings of the Odour Management Conference & Technology Showcase (OMCTS). Scentroid, Toronto, ON.
Freeman, T., Cudmore, R., 2002. Review of Odour Management in New Zealand. Air Quality Technical Report 24. New Zealand Ministry of Environment, Wellington, p. 163.
Generalitat de Cataluña, 2005. Borrador del anteproyecto de ley contra la contaminación odorífera. Departamento de Medio Ambiente y Vivienda, Dirección General de Calidad Ambiental, Barcelona, p. 26.
Gifford, F., 1959. Statistical properties of a fluctuating plume dispersion model. In: Landsberg, H.E., Mieghem, J.V. (Eds.), Advances in Geophysics. Elsevier, pp. 117–137.
Gifford, F., 1960. Peak to average concentration ratios according to a fluctuating plume dispersion model. Int. J. Air Pollut. 3, 253–260.
GOAA, 2008. Guideline on Odour in Ambient Air GOAA. Detection and Assessment of Odour in Ambient Air. Second Version, Berlin, Germany.
Godish, T., 2004. Air Quality, 4 ed. CRC Press, Boca Raton, Florida.
Gostelow, P., Parsons, S.A., Stuetz, R.M., 2001. Odour measurements for sewage treatment works. Water Res. 35, 579–597.
Gouvernement wallon, 2009. 18 juin 2009-Arrêté du Gouvernement wallon déterminant les conditions sectorielles relatives aux installations de compostage lorsque la quantité de matière entreposée est supérieure ou égale à 500 m3 et modifiant l'arrêté du Gouvernement wallon du 4 juillet 2002 relative à la procédure et à diverses mesures d'exécution du décret du 11 mars 1999 relatif au permis d'environnement (M.B. 11.09.2009).
Government Gazette, 2005. No. 39 of 2004: National Environment Management: Air Quality Act, 2004, vol. 476. South Africa, Cape Town, p. 56, 24 February 2005, No. 27318.
Griffiths, K.D., 2014. Disentangling the frequency and intensity dimensions of nuisance odour, and implications for jurisdictional odour impact criteria. Atmos. Environ. 90, 125–132.
Gutiérrez, M.C., Martín, M.A., Pagans, E., Vera, L., García-Olmo, J., Chica, A.F., 2015. Dynamic olfactometry and GC–TOFMS to monitor the efficiency of an industrial biofilter. Sci. Total Environ. 512–513, 572–581.
Hayes, E.T., Curran, T.P., Dodd, V.A., 2006. A dispersion modelling approach to determine the odour impact of intensive poultry production units in Ireland. Bioresour. Technol. 97, 1773–1779.
Hayes, J.E., Stevenson, R.J., Stuetz, R.M., 2014. The impact of malodour on communities: a review of assessment techniques. Sci. Total Environ. 500–501, 395–407.
Hobson, J., Yang, G., 2014. Odour Control in Wastewater Treatment – a Technical Reference Document. UK Water Industry Research Limited, London.
Högström, U., 1972. A method for predicting odour frequencies from a point source. Atmos. Environ. 6, 103–121 (1967).
Hurley, P., 2008. TAPM V4. User Manual. CSIRO Marine and Atmospheric Research Internal Report No. 5. ISBN: 978-1-921424-73-1.
ICONTEC, 2011. Instituto Colombiano de Normas Técnicas y Certificación. NTC 5880: Calidad del Aire. Determinación de la Concentración de Olor por Olfatometría Dinámica. ICONTEC, Bogotá.
ICONTEC, 2013. Instituto Colombiano de Normas Técnicas y Certificación. NTC 6012-1: Efectos y Evaluación de los Olores. Evaluación Sicométrica de las Molestias por Olores. Cuestionarios. ICONTEC, Bogotá, p. 47.
ICONTEC, 2014a. Instituto Colombiano de Normas Técnicas y Certificación. NTC 6049–1: Medición de Impacto de Olor Mediante Inspección en Campo.

Medición de la Frecuencia del Impacto de Olores Reconocibles. Medición de Malla. ICONTEC, Bogotá.
ICONTEC, 2014b. Instituto Colombiano de Normas Técnicas y Certificación. NTC 6049–2: Medición de Impacto de Olor Mediante Inspección en Campo. Medición de la Frecuencia del Impacto de Olores Reconocibles. Medición de Pluma. ICONTEC, Bogotá.
IMEP, 2013. Israel's Ministry of Environmental Protection. Guideline on Odours (In Hebrew). Available at: http://www.sviva.gov.il. Acessed in 23 May 2016.
IMEP, 2016. Israel's Ministry of Environmental Protection. Pollution and Nuisances. Available at: http://www.sviva.gov.il. Acessed in 23 May 2016.
InfoMil, 2014. Kenniscentrum InfoMil. Digitale NeR. Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, p. 307.
InfoMil, 2016a. Kenniscentrum InfoMil. Geur: Lokaal Geurbeleid. Available at: http://www.infomil.nl/. Acessed in 18 July 2016.
InfoMil, 2016b. Kenniscentrum InfoMil. Handleiding geur: bepalen van het aanvaardbaar hinderniveau van industrie en bedrijven (niet veehouderijen). 21 juni 2016. Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, p. 161.
InfoMil, 2016c. Kenniscentrum InfoMil. Handreiking geurhinder en veehouderij. 21 juni 2016. Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, p. 93.
InfoMil, 2016d. Kenniscentrum InfoMil. Handreiking Nieuw Nationaal Model II. 21 juni 2016. Rijkswaterstaat, Ministerie van Infrastructuur en Milieu.
InfoMil, 2016e. Kenniscentrum InfoMil. Handreiking Nieuw Nationaal Model. 21 juni 2016. Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, p. 53.
INN, 2010. Instituto Nacional de Normalización. NCh3190: Calidad del aire – Determinación de la concentración de olor por olfatometría dinámica. INN, Santiago.
INN, 2015a. Instituto Nacional de Normalización. NCh3386: Calidad del aire – Muestreo estático para olfatometría. INN, Santiago.
INN, 2015b. Instituto Nacional de Normalización. NCh3387: Calidad del aire – Evaluación de la molestia por olores – Encuesta. INN, Santiago.
Iwasaki, Y., 2003. The History of Odor Measurement in Japan and Triangle Odor Bag Method. Ministry of the Environment. Government of Japan, pp. 37–47.
Janicke, L., Ahrens, D., Hartmann, U., Müller, W.J., 2004. Development of the odour dispersion model Austal 2000G in Germany. In: Environmental Odour Management Conference, Cologne. VDI Berichte 1850, pp. 411–417.
JORF, 2003. Arrêté du 12 février 2003 relatif aux prescriptions applicables aux installations classées soumises à autorisation sous la rubrique 2730 traitement de sous-produits d'origine animale, y compris débris, issues et cadavres, à l'exclusion des activités visées par d'autres rubriques de la nomenclature, des établissements de diagnostic, de recherche et d'enseignement. J. Off. de Républ. Française.
JORF, 2008. Arrêté du 22/04/08 fixant les règles techniques auxquelles doivent satisfaire les installations de compostage soumises à autorisation en application du titre Ier du livre V du code de l'environnement. JORF n° 114 du 17 mai 2008. J. Off. de Républ. Française.
Juneng, L., Latif, M.T., Tangang, F., 2011. Factors influencing the variations of PM10 aerosol dust in Klang Valley, Malaysia during the summer. Atmos. Environ. 45, 4370–4378.
Kamigawara, K., 2003. Odor Regulation and Odor Measurement in Japan. Odor Measurement Review, Ministry of the Environment. Government of Japan, pp. 48–53.
Kim, K.-H., 2016. The need for practical input data for modeling odor nuisance effects due to a municipal solid waste landfill in the surrounding environment. Environ. Int. 87, 116–117.
Kim, K.-H., Kim, Y.-H., 2014. Composition of key offensive odorants released from fresh food materials. Atmos. Environ. 89, 443–452.
Kim, K.-H., Park, S.-Y., 2008. A comparative analysis of malodor samples between direct (olfactometry) and indirect (instrumental) methods. Atmos. Environ. 42, 5061–5070.
Klarenbeek, J.V., Ogink, N.W.M., van der Voet, H., 2014. Odor measurements according to EN 13725: a statistical analysis of variance components. Atmos. Environ. 86, 9–15.
KLIF, 2013. Veileder - Regulering Av Luktutslipp I Tillatelser Etter Forurensningsloven. TA 3019:2013. Klima og Forurensningsdirektoratet, Oslo, p. 67.
KMOE, 2008. Annual Report of Ambient Air Quality in Korea. Korean Ministry of Environment.
Laor, Y., Parker, D., Pagé, T., 2014. Measurement, prediction, and monitoring of odors in the environment: a critical review. Rev. Chem. Eng. 30.
Leduc, R., 2005. Guide de la modélisation de la dispersion atmosphéric. Ministère du Développement durable, de l'Environnement et des Parcs. Direction du suivi de l'état de l'environnement, Québec, p. 38.
Leonardos, G., Kendall, D., Barnard, N., 1969. Odor threshold determinations of 53 odorant chemicals. J. Air Pollut. Control Assoc. 19, 91–95.
LNE, 2006. Geurregelgeving in Een Notedop. Departement Leefmilieu, Natuur en Energie. Available at: http://www.lne.be. Acessed in 06 June 2016.
LNE, 2008. Achtergronddocument Bij Het Visiedocument 'De Weg Naar Een Duurzaam Geurbeleid'. Departement Leefmilieu, Natuur en Energie, p. 108.
LNE, 2010. Departement Leefmilieu, Natuur en Energie. Handleiding: Behandeling van geurklachten door lokale overheden, versie 3. LNE, Brussel, p. 82.
LNE, 2015. Lijst met geactualiseerde emissiefactoren voor ammoniak, geur en fijn stof. Bijlage Richtlijnenboek Landbouwdieren. Versie 20/03/2015. Departement Leefmilieu, Natuur en Energie, p. 13.
Lorimer, G., 1986. The AUSPLUME Gaussian Plume Dispersion Model. Contract EPA/86–02. Environment Protection Authority, Melbourne, Victoria, Australia.
Mahin, T., 2003. Measurement and Regulation of Odors in the USA. Ministry of the Environment, Government of Japan, pp. 62–68. Odor Measurement Review.
Mahin, T.D., 2001. Comparison of different approaches used to regulate odours around the world. Water Sci. Technol. 44, 87–102.
Mainland, J., Sobel, N., 2006. The sniff is part of the olfactory percept. Chem. Senses 31, 181–196.
Manitoba, 2005. Manitoba Environmental Programs & Strategies. Manitoba Ambient Air Quality Criteria, p. 4.
Manitoba Conservation, 2006. Air Dispersion Modelling Protocol for Assessing Odour Impacts in Manitoba - Draft. Air Quality Section Programs Division. Report No. 2006-0x, p. 11.
McGinley, C.M., McGinley, M.A., 2002. Odor testing biosolids for decision making. In: Proceedings of the Annual Residuals and Biosolids Management Conference: Privatization, Innovation and Optimization: How to Do More for Less. Water Environmental Federation, Austin, TX.
McGinley, M.A., Mann, J., 1998. European versus United States odour/odor standards of evaluation. In: Water Environment Federation 71st Annual Conference., Orlando, FL: 3–7 October 1998.
McGinley, M.A., McGinley, C.M., 2014. An overview of odour regulation throughout North America. In: Proceedings of the 1st International Seminar of Odours in the Environment. Olores.Org, Santiago, Chile.
McGinley, M.A., McGinley, C.M., Mann, J., 2000. Olfactomatics: Applied Mathematics for Odor Testing. Proceedings of the Odors and VOC Emissions. Water Environmental Federation, Cincinnati, OH.
MDDEP, 2011. Ministère du Développement durable, de l'Environnement et des Parcs. Lignes directrices pour l'encadrement des activités de biométhanisation. MDDEP, Québec, p. 57.
MDDEP, 2012. Ministère du Développement durable, de l'Environnement et des Parcs. Lignes directrices pour l'encadrement des activités de compostage. MDDEP, Québec, p. 76.
MEDDE, 2016a. Ministère de l'Environnement, de l'Energie et de la Mer. Les odeurs. Available at: http://www.installationsclassees.developpement-durable.gouv.fr/. Acessed in 21 April 2016.
MEDDE, 2016b. Ministère de l'Environnement, de l'Energie et de la Mer. Réglementation sur la qualité de l'air. Available at: http://www.developpement-durable.gouv.fr/. Acessed in 21 April 2016.
Melse, R.W., Ogink, N.W.M., Rulkens, W.H., 2009. Overview of European and Netherlands' regulations on airborne emissions from intensive livestock production with a focus on the application of air scrubbers. Biosyst. Eng. 104, 289–298.
MEP, 2016. People's Republic of China Ministry of Environmental Protection. Emission Standards for Odor Pollutants (GB 14554–93; Put into Effect as of January 15, 1994). Available at: http://english.mep.gov.cn/. Acessed in 10 may 2016.
MfE, 2003. New Zealand Ministry of the Environment. Good Practice Guide for Assessing and Managing Odour in New Zealand. MfE, Wellington, p. 67. Air Quality Report 36.
Miedema, H.M.E., Walpot, J.I., Vos, H., Steunenberg, C.F., 2000. Exposure-annoyance relationships for odour from industrial sources. Atmos. Environ. 34, 2927–2936.
Miljøcenter, 2002. Vejledende retningslinier for vurdering af lugt og begrænsning af gener fra stalde. FMK, Odense SØ, p. 23.
Miljøministeriet, 2006. Faglig rapport vedrørende en ny lugtvejledning for husdyrbrug. Skov- og Naturstyrelsen, p. 66.
Miljøstyrelsen, 2011. Lugt. Version 2.0–14. Januar 2011. Available at: http://www2.mst.dk/Wiki/Husdyrvejledning.Lugt.ashx. Acessed in 09 June 2016.
MINAMBIENTE, 2013. Ministerio de Ambiente y Desarrollo Sostenible. Resolución 1541 de 2013 (noviembre 12). Por la cual se establecen los niveles permisibles de calidad del aire o de inmisión, el procedimiento para la evaluación de actividades que generan olores ofensivos y se dictan otras disposiciones. Bogota: Diario Oficial No. 48.975, 15 nov. 2013.
MINAMBIENTE, 2014. Ministerio de Ambiente y Desarrollo Sostenible. Resolución 2087 de 2014 (diciembre 16). Por la cual se adopta el protocolo para el monitoreo, control y vigilancia de olores ofensivos. Bogota: Diario Oficial No. 49.380, 30 dic. 2014.
Ministry of the Environment, 2013. Strategy for Odors Management in Chile (2014 – 2017). Division of Air Quality, Santiago, Chile. September 2013.
MOE, 2003a. Odor Index Regulation and Triangular Odor Bag Method. Ministry of Environment. Government of Japan. Available at: http://www.env.go.jp. Acessed in 10 May 2016.
MOE, 2003b. The Offensive Odour Control Law in Japan. Ministry of Environment. Government of Japan. Available at: http://www.env.go.jp. Acessed in 10 May 2016.
Morosini, C., Favaron, M., Cogo, D., Basilico, D.I., 2016. Gestione e trattamento degli odori in regione lombardia: indagine su 35 impianti di depurazione delle acque reflue. Ing. dell'Ambiente 3, 1–14.
Needham, C.E., Freeman, T.J., 2009. Case studies in the use of source specific odour modelling guidelines. In: Proceedings of the Water New Zealand's 51st Annual Conference & Expo. Water New Zealand Annual Conference, Rotorua, NZ.
NEN, 2005. Nederlands Normalisatie-instituut. NVN 2818 (nl): Geurkwaliteit - Sensorische bepaling van de hedonische waarde van een geur met een olfactometer. NEN, Delft.
Nicell, J., 1986. Preliminary Assessment of the Odour Impact Model as a Regulatory. Department of Chemical Engineering. University of Windsor, Windsor, p. 297.
Nicell, J.A., 2009. Assessment and regulation of odour impacts. Atmos. Environ. 43, 196–206.
Nicolas, J., Delva, J., Cobut, P., Romain, A.-C., 2008. Development and validating

procedure of a formula to calculate a minimum separation distance from piggeries and poultry facilities to sensitive receptors. Atmos. Environ. 42, 7087–7095.
NIEA, 2012. Northern Ireland Environment Agency. Odour Impact Assessment Guidance for Permitted and Licensed Sites. Version 1, p. 13.
OAW, 1994. Umweltwissenschaftliche Grundlagen und Zielsetzungen im Rahmen des Nationalen Umweltplans für die Bereiche Klima, Luft, Geruch und Larm. In: Osterreichische Akademie der Wis-senschaften (Ed.), Kommission für Reinhaltung der Luft. Bundesministeriums für Umwelt, Jugend und Familie, Wien. Schriftenreihe der Sektion I, Band 17.
Olesen, H.R., Løfstrøm, P., Berkowicz, R., Ketzel, M., 2005. Regulatory Odour Model Development: Survey of Modelling Tools and Datasets with Focus on Building Effects. NERI Technical Report No. 541. National Environmental Research Institute, Ministry of the Environment, p. 60.
OMOE, 2009. Ontario Ministry of the Environment. Air Dispersion Modelling Guideline for Ontario. Version 2.0. OMOE, Toronto, p. 151.
Paraná, 2014. Secretária de Estado do Meio Ambiente e Recursos Hídricos (SEMA). Resolução SEMA nº 016, de 26 de março de 2014. Define critérios para o controle da qualidade do ar. Available at: www.iap.pr.gov.br. Acessed in 18 fev. 2016.
Park, S.J., 2004. State of the Art of the Deodorizing Technology in Korea. Proceedings of the East Asia Workshop on Odor Measurement and Control Review. Ministry of Environment, Tokyo, JP.
Pettarin, N., Campolo, M., Soldati, A., 2015. Urban air pollution by odor sources: short time prediction. Atmos. Environ. 122, 74–82.
Piringer, M., Knauder, W., Petz, E., Schauberger, G., 2014. Site-dependent decrease of odour-related peak-to-mean factors with distance. Adv. Sci. Res. 11, 69–73.
Piringer, M., Knauder, W., Petz, E., Schauberger, G., 2015. A comparison of separation distances against odour annoyance calculated with two models. Atmos. Environ. 116, 22–35.
Piringer, M., Knauder, W., Petz, E., Schauberger, G., 2016a. Factors influencing separation distances against odour annoyance calculated by Gaussian and Lagrangian dispersion models. Atmos. Environ. 140, 69–83.
Piringer, M., Knauder, W., Petz, E., Schauberger, G., 2016b. Factors influencing separation distances against odour annoyance calculated by Gaussian and Lagrangian dispersion models. Atmos. Environ. http://dx.doi.org/10.1016/j.atmosenv.2016.05.056.
Piringer, M., Petz, E., Groehn, I., Schauberger, G., 2007. A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM). Atmos. Environ. 41, 1725–1735.
PME, 2004. Environmental Standards: Control of Emissions to Air from Stationary Sources. Kingdom of Saudi Arabia. Presidency of Meteorology and Environment, p. 13.
PME, 2012. Environmental Standards: Ambient Air Quality. Kingdom of Saudi Arabia. Presidency of Meteorology and Environment, p. 6.
Pullen, J., Vawda, Y., 2007. Review of Dispersion Modelling for Odour Predictions. Technical Report. UK Environment Agency, Bristol, p. 131.
Ramsdell Jr., J.V., Hinos, W.T., 1971. Concentration fluctuations and peak-to-mean concentration ratios in plumes from a ground-level continuous point source. Atmos. Environ. 5, 483–495 (1967).
Ranzato, L., Barausse, A., Mantovani, A., Pittarello, A., Benzo, M., Palmeri, L., 2012. A comparison of methods for the assessment of odor impacts on air quality: field inspection (VDI 3940) and the air dispersion model CALPUFF. Atmos. Environ. 61, 570–579.
Regione Lombardia, 2012. Deliberazione Giunta regionale 15 febbraio 2012-n. IX/3018. Determinazioni generali in merito alla caratterizzazione delle emissioni gassose in atmosfera derivanti da attività a forte impatto odorigeno. Bollettino Ufficiale 20 febbraio 2012, pp. 18–49.
Royal Commission, 2004. Royal Commission for Jubail and Yanbu. Royal Commission Environmental Regulations, vol. I. Environmental Control Department, Kingdom of Saudi Arabia, p. 107.
Ruijten, M.W.M.M., Van Doorn, R., Van Harreveld, A.P., 2009. Assessment of Odour Annoyance in Chemical Emergency Management. RIVM Report 609200001, p. 56. National Institute for Public Health and Environment, Bilthoven: RIVM.
RWDI Air Inc, 2005. Odour Management in British Columbia: Review and Recommendations. Final Report to the Ministry of Water, Land and Air Protection, BC.
SAEPA, 2006. South Australian Environment Protection Authority. EPA 386/06: Air Quality Impact Assessment Using Design Ground Level Pollutant Concentrations (DGLCs). Adelaide, p. 12.
SAEPA, 2007a. South Australian Environment Protection Authority. EPA 373/07: Odour Assessment Using Odour Source Modelling. Adelaide, p. 7.
SAEPA, 2007b. South Australian Environment Protection Authority. Guidelines for Separation Distances. Adelaide, p. 32.
Santa Catarina, 2009. Lei Estadual Nº 14.675, de 13 de abril de 2009. Institui o Código Estadual do Meio Ambiente e estabelece outras providências. ALESC, Florianópolis.
São Paulo, 1976. Decreto Nº 8.468, de 08 de setembro de 1976. Aprova o Regulamento da Lei nº 997, de 31 de maio de 1976, que dispõe sobre a Prevenção e o Controle da Poluição do Meio Ambiente. Available at: http://www.cetesb.sp.gov.br. Acessed in 04 March 2016.
São Paulo, 2013. Decreto nº 59.113, de 23 de abril de 2013. Estabelece novos padrões de qualidade do ar e dá providências correlatas. São Paulo, SP, D.O.E., Poder Executivo, Seção I, 24 abr. 2013, v. 123, nº 76.
Schauberger, G., Piringer, M., 2012. Assessment of separation distances to avoid odour annoyance: interaction between odour impact criteria and peak-to-mean factors. Chem. Eng. Trans. 30, 13–18.
Schauberger, G., Piringer, M., Petz, E., 2000. Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM). Atmos. Environ. 34, 4839–4851.
Schauberger, G., Piringer, M., Petz, E., 2013. Corrigendum to “Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM)”. Atmos. Environ. 67, 459–460 [Atmos. Environ. 34 (2000) 4839–4851].
Schauberger, G., Piringer, M., Schmitzer, R., Kamp, M., Sowa, A., Koch, R., Eckhof, W., Grimm, E., Kypke, J., Hartung, E., 2012a. Concept to assess the human perception of odour by estimating short-time peak concentrations from one-hour mean values. Reply to a comment by Janicke et al. Atmos. Environ. 54, 624–628.
Schauberger, G., Schmitzer, R., Kamp, M., Sowa, A., Koch, R., Eckhof, W., Eichler, F., Grimm, E., Kypke, J., Hartung, E., 2012b. Empirical model derived from dispersion calculations to determine separation distances between livestock buildings and residential areas to avoid odour nuisance. Atmos. Environ. 46, 508–515.
Scire, J.S., Strimaitis, D.G., Yamartino, R.J., 2000. A User's Guide to the CALPUFF Dispersion Model (Version 5). Earth Tech Inc, Concord, Massachusetts.
Seinfeld, J.H., Pandis, S.N., 2006. Atmospheric Chemistry and Physics from Air Pollution to Climate Change, 2 ed. Wiley, New Jersey.
SEPA, 2010. Scottish Environment Protection Agency. Odour Guidance 2010. Version 1, p. 95. Available at: http://www.sepa.org.uk/. Acessed in: 11 May 2016.
Smith, M., 1973. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. American Society for Mechanical Engineers, New York.
Sommer-Quabach, E., Piringer, M., Petz, E., Schauberger, G., 2014. Comparability of separation distances between odour sources and residential areas determined by various national odour impact criteria. Atmos. Environ. 95, 20–28.
Stevens, S.S., 1960. The psychophysics of sensory function. Am. Sci. 48, 226–253.
Stull, R.B., 1988. An Introduction to Boundary Layer Meteorology, 1 ed. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Sucker, K., Both, R., Bischoff, M., Guski, R., Krämer, U., Winneke, G., 2008a. Odor frequency and odor annoyance Part II: dose response associations and their modification by hedonic tone. Int. Arch. Occup. Environ. Health 81, 683–694. Springer-Verlag.
Sucker, K., Both, R., Bischoff, M., Guski, R., Winneke, G., 2008b. Odor frequency and odor annoyance. Part I: assessment of frequency, intensity and hedonic tone of environmental odors in the field. Int. Arch. Occup. Environ. Health 81, 671–682. Springer-Verlag.
Suffet, I.H., Burlingame, G.F., Rosenfeld, P.F., Bruchet, A., 2004. The value of an odor-quality-wheel classification scheme for wastewater treatment plants. Water Sci. Technol. 50, 25–32.
Suffet, I.H., Decottignies, V., Senante, E., Bruchet, A., 2009. Sensory assessment and characterization of odor nuisance emissions during the composting of wastewater biosolids. Water Environ. Res. 81, 670–679.
Suffet, I.H., Rosenfeld, P., 2007. The anatomy of odour wheels for odours of drinking water, wastewater, compost and the urban environment. Water Sci. Technol. 55, 335–344.
TA-Luft, 2002. Technische Anleitung zur Reinhaltung der Luft. First General Administrative Regulation Pertaining the Federal Immission Control Act. Federal Ministry for Environment, Nature Conservation and Nuclear Safety, p. 252. English Version.
Tsai, C.-J., Chen, M.-L., Chang, K.-F., Chang, F.-K., Mao, I.F., 2009. The pollution characteristics of odor, volatile organochlorinated compounds and polycyclic aromatic hydrocarbons emitted from plastic waste recycling plants. Chemosphere 74, 1104–1110.
Tsai, W.-T., 2016. Current status of air toxics management and its strategies for controlling emissions in Taiwan. Toxics 4, 8.
Turner, D.B., 1994. Workbook of Atmospheric Dispersion Estimates. An Introduction to Dispersion Modeling, 2 ed. CRC Press, Boca Raton, Florida.
URS Holdings, 2006. Anteproyecto de Normas para el Control de Olores Molestos Panamá, p. 28.
van Belois, H., Both, R., 2004. Assessment of odour nuisance at the border of Holland and Germany. In: Environmental Odour Management International Conference. VDI-berichte 1850, Cologne, Germany.
Van Broeck, G., Van Elst, T., 2003. The way to a sustainable odour policy in Flanders. In: Proceedings of the 2nd IWA Odour Conference on Odour & VOCs: Measurement, Regulation and Control Techniques, Singapore, 14–17 September.
Van Harreveld, A.P., 2001. From odorant formation to odour nuisance: new definitions for discussing a complex process. Water Sci. Technol. 44, 9–15.
Van Harreveld, A.P., 2003. Odor regulation and the history of odormeasurement in Europe. In: Proceedings of the International Odor Conference. Ministry of Environment, Tokyo, JP.
Van Harreveld, A.P., 2014. Progress in the review of EN13725: focus on sampling and uncertainty. Chem. Eng. Trans. 40.
VDI, 1992. Verein Deutscher Ingenieure. VDI 3882 Part 1: Olfactometry: Determination of Odour Intensity. Beuth Verlag GmbH, Berlin.
VDI, 1994. Verein Deutscher Ingenieure. VDI 3882 Part 2: Olfactometry: Determination of Hedonic Odour Tone. Beuth Verlag GmbH, Berlin.
VDI, 2001. Verein Deutscher Ingenieure. VDI 3945 Part 3: Environmental Meteorology - Atmospheric Dispersion Models - Particle Model. Beuth Verlag GmbH, Berlin.
VDI, 2006. Verein Deutscher Ingenieure. VDI 3940 Part 1: Measurement of Odour Impact by Field Inspection; Measurement of the Impact Frequency of Recognizable Odours, Grid Measurement. Beuth Verlag GmbH, Berlin.
VDI, 2010a. Verein Deutscher Ingenieure. VDI 3940 Part 3: Measurement of Odour Impact by Field Inspection - Determination of Odour Intensity and Hedonic

Odour Tone. Beuth Verlag GmbH, Berlin.
VDI, 2010b. Verein Deutscher Ingenieure. VDI 3940 Part 4: Determination of the Hedonic Odour Tone - Polarity Profiles. Beuth Verlag GmbH, Berlin.
VDI, 2011. Verein Deutscher Ingenieure. VDI 3880: Olfactometry - Static Sampling. Beuth Verlag GmbH, Berlin.
VDI, 2015a. Verein Deutscher Ingenieure. VDI 3883 Part 1: Effects and Assessment of Odours - Assessment of Odour Annoyance - Questionnaires. Beuth Verlag GmbH, Berlin.
VDI, 2015b. Verein Deutscher Ingenieure. VDI 3884-Part 1: Olfactometry - Determination of Odour Concentration by Dynamic Olfactometry - Supplementary Instructions for Application of DIN EN 13725. Beuth Verlag GmbH, Berlin.
Venkatram, A., 2002. Accounting for averaging time in air pollution modeling. Atmos. Environ. 36, 2165–2170.
Vieira de Melo, A.M., Santos, J.M., Mavroidis, I., Reis Junior, N.C., 2012. Modelling of odour dispersion around a pig farm building complex using AERMOD and CALPUFF. Comparison with wind tunnel results. Build. Environ. 56, 8–20.
VITO, 2012. Richtlijnenboek Lucht: Geactualiseerde Versie. Projectnummer: 222058, p. 212.
VROM, 2006a. De Staatssecretaris van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Regeling geurhinder en veehouderij. 8 december 2006, Geldend van 31-03-2016 t/m heden. Den Haag, Nederland.
VROM, 2006b. De Staatssecretaris van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Wet geurhinder en veehouderij. 5 oktober 2006, Geldend van 01-01-2013 t/m heden. 's-Gravenhage, Nederland.
VROM, 2007. De Minister van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. De Staatssecretaris van Verkeer en Waterstaat. Activiteitenbesluit milieubeheer. 19 oktober 2007, Geldend van 01-01-2013 t/m heden. 's-Gravenhage, Nederland.
WAEPA, 2002. Western Australia Environmental Protection Authority. EPA Guidance Statement No. 47: Guidance Statement for Assessment of Odour Impacts from New Proposals.
WAEPA, 2005. Western Australia Environmental Protection Authority. Guidance Statement No. 3: Guidance for the Assessment of Environmental Factors (In Accordance with the Environmental Protection Act 1986). Separation Distances between Industrial and Sensitive Land Uses, p. 59.
Walgraeve, C., Van Huffel, K., Bruneel, J., Van Langenhove, H., 2015. Evaluation of the performance of field olfactometers by selected ion flow tube mass spectrometry. Biosyst. Eng. 137, 84–94.
Watts, P.J., Sweeten, J.M., 1995. Toward a better regulatory model for odour. In: Proceedings of the Xth Feedlot Association of Australia Conference. FeedlotWaste Management Conference, Benowa, QLD.
Willems, E., Monseré, T., Dierckx, J., 2015. Geactualiseerd richtlijnenboek milieueffectrapportage 'Basisrichtlijnen per activiteitengroep – Landbouwdieren'. Gent: ABO NV, juni 2011 – aangepast maart 2015, p. 146.
Zannetti, P., 1993. Numerical simulation modelling of air pollution: an overview. In: Zannetti, P. (Ed.), Air Pollution. Computational Mechanics Publications, Southampton, pp. 3–14.

Please cite this article in press as: Brancher, M., et al., A review of odour impact criteria in selected countries around the world, Chemosphere (2016), http://dx.doi.org/10.1016/j.chemosphere.2016.11.160