Odour Nuisance Index as urban planning tool

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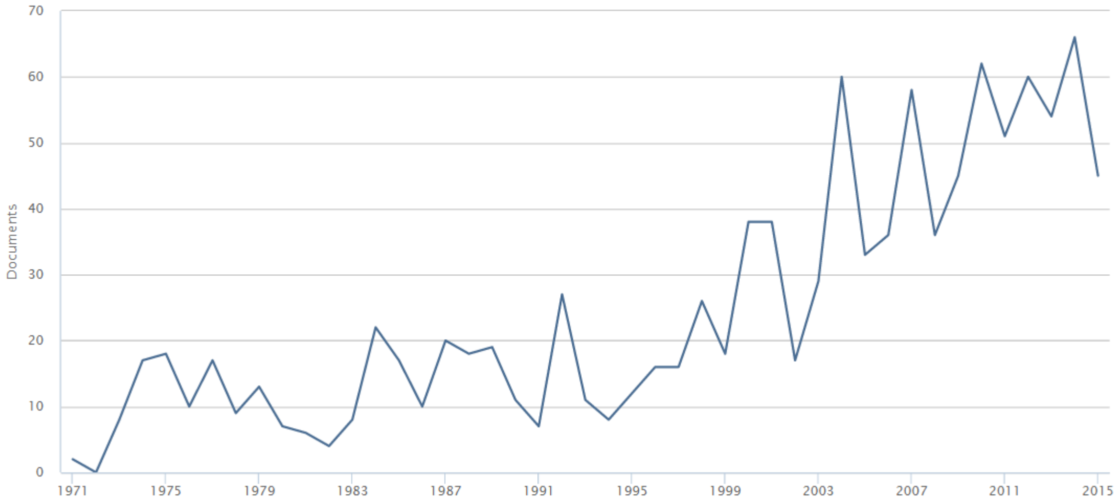
This paper analyzes the state of the art of the methods and models used for the characterization of odour annoyance and it preliminary advances proposals for the evaluation of the olfactory nuisance.
The use of a sensorial technique, such as dynamic olfactometry, is proposed for the analysis of odour concentrations, odour emission rates and odour dispersions.
A simple model for the quantification of environmental odour nuisance, based on the use of FIDOL factors, i.e. frequency, intensity, duration, hedonic tone and location, is developed.

Keywords: annoyance, nuisance, impact assessment, offensiveness, location

1. Introduction

Odours do not directly represent a problem for human health, but they create problems of nuisance, adversely affecting the wellness of citizens. The olfactory nuisance actually is the biggest cause of public complaints initiatives in North America and in Europe (Leonardos, 1995). Prolonged exposure to odours may cause negative effects on humans, including emotional stress, anxiety, discomfort, headaches, depression, eye irritation, respiratory problems, nausea and vomiting (Wilson, et al., 1980), (Brennhairhaian, 1993). Consequently, the presence of odours can lead to the loss of dwelling amenity (Freeman, et al., 2002) and to a lowering of the corresponding real estate value (Environmental Agency, 2011).
Both the loss of amenity and physical disorders, can lead to complaints, especially when the presence of an odour sensation is often repeated over time.
The interest of the scientific world with respect to the problems related to odour pollution has therefore increased over the years. As an example, Figure 1 shows the trend of the publications regarding the topic of odour nuisance.

Fig. 1: Number of documents in SCOPUS using as key words “odour annoyance” or “odour nuisance”



In order to design appropriate strategies for odour emissions control, it is necessary to develop suitable scientific methods to univocally quantify odour (Hobson, 1995), thereby eliminating the mentality for which odour characterization should be treated more as an art than as a science (Jiang, 1996). The use of chemical analysis for odour quantification has proven to be scarcely reliable or not representative of the real situation (Brennan, 1993), (Preti, et al., 1993), (Cain, et al., 1995), (Zhao, et al., 2014).

Instead, it is more and more frequent to apply sensorial techniques, based on the responses of a selected panel of assessors, in order to quantify odour (Hair, et al., 2010). Among those, dynamic olfactometry is the most diffuse, because of its repeatability, especially after the introduction of the EN 13725:2003 (CEN, 2003). Since the introduction of a standardized method for odour measurement, many academic studies focused on the evaluation and quantification of odour emissions from industrial facilities. Most of these studies generally aimed to evaluate solely the amount of odour emitted and eventually apply dispersion models to assess to which extent these emissions impact on the surroundings.

However, it is currently widespread opinion that this kind of assessment only represents one of different aspects that, when combined, may cause olfactory nuisance. As it is known from the literature, there are five factors, called FIDOL (Watts, 1995), which are the Frequency, Intensity, Duration, Offensiveness and Location of odour perception, that play a role in the definition of odour nuisance. For these reasons, the exclusive study of odour concentration cannot be fully representative of the environmental nuisance caused by an odour emission, as this neglects various parameters that have to be considered in order to quantify the effective discomfort.

In details, the five parameters can be so explained (Freeman, et al., 2002; Nicell, 2009; Griffiths, 2014):

- Frequency: Represents how often a receptor perceives an odour
- Intensity: Describes the strength of the odour event. It's directly correlated to the odour concentration

- Duration: It’s the length of time people are exposed to odour. If a dispersion model is used, this duration parameter is dependent on the time step
- Offensiveness: the odours are very different between each other. Offensiveness is a parameter that describe how much an odour is unpleasant
- Location: It’s the place where an odour is perceived.

The purpose of this study is to explore the topic of objectification and quantification of the odour nuisance. The aim is therefore to make a proposal of a method for the evaluation of discomfort, which involves the evaluation of the contribution of FIDOL parameters to increase the reliability and completeness of the assessment.

2. Methods

2.1 Current methods for odour impact assessment

One common method for the prediction of odour emissions from an activity is the use of OEFs (Odour Emission Factors). OEFs are developed in analogy with the emission factors defined by the United States Environmental Protection Agency (1995). In accordance with it, an Emission Factor is a representative value relating the amount of a pollutant released into the atmosphere, to a certain type of related activity. Numerous studies deal with this type of assessment factors for different types of plants (Hair, et al., 2009; Mielcarek, et al., 2015; Sironi, et al, 2005; Sironi et al, 2007). OEFs are typically evaluated upstream of abatement systems. For this reason, in order to estimate odour emissions into the atmosphere from non-existing plants, it is necessary to hypothesize the efficiency of such systems.
Instead, when making evaluations about an existing plant, the best strategy to use is the direct emission sampling and analysis. The parameter that is used, in this case, is the OER (Odour Emission Rate), calculated as:

$$\mathrm{OER} = \mathrm{Q} \cdot \mathrm{C_{od}} = \left[\frac{\mathrm{ou_E}}{\mathrm{s}}\right] \qquad (1)$$

where Q is the airflow coming from an emission point, normalized at 20 °C [m^3/s] and C_{od} is the odour concentration of the emission [ou_E/m^3] measured by dynamic olfactometry, according to the EN 13725:2003.
An older approach for some regulations was based on the definition of limit values at emissions in terms of odour concentration or odour emission rate (e.g., D.G.R.n.7/12764, 2003; D.G.R. n.1495, 2001; S 2205-1, 1997), which is the reason why some odour impact assessment approaches involved only the quantification of emissions. However, the evaluation of the OER alone doesn’t give any information about how an emission will affect potential receptors.
In order to move in the direction of evaluating odour impact at receptors instead that at the source, the use of dispersion models has been spreading out recently. Models allow to simulate how odour emissions disperse in the atmosphere and thus to evaluate the ground odour concentration in a defined space-time domain. Currently

most of the regulations in the world in the field of odour are based on a dispersion modelling approach (Capelli et al., 2013).

Input data required for this kind of models are meteorological, orographic and emission data. The output is the ground odour concentration in each point of the sampling grid, estimated in each time interval considered, averaged over the integration time. In order to avoid to increase too much the computation time and the input data complexity, the time step on which the model runs is generally one hour. For this reason, the ground odour concentration values calculated by the model on every cell of the simulation domain represents the odour concentration averaged over one hour. Since the odour event can have a lower duration with respect to an hour, the use of corrective so called “peak-to-mean” factors becomes necessary. These factors are multiplied by the 1-h averaged odour concentration value, thus giving the peak odour concentration within the hour (Schauberger, et al., 2012). The peak-to-mean factor is defined as:

$$F = \frac{Cp}{Cm} \qquad (2)$$

where F is the peak-to-mean ratio, C_p is the peak concentration and C_m is the 1-h averaged (mean) concentration.

Therefore, the output data obtained by means of odour dispersion modelling are typically the “peak” odour concentration values at all points of space-time domain obtained through the application of this “safety” factor F. The applied peak-to-mean factors vary widely from country to country (Piringer, et al., 2013).

Finally, being odour a pollutant that is not constantly present at the receptor, it is common that odour impact is assessed by evaluating not the average odour concentration over the simulation period, but a given percentile of the odour concentration values estimated over the time domain. This means that odour impact is defined through the frequency with which a given odour concentration values is exceeded in the simulation domain. The authorities and regulators are tending to use these parameters to set odour impact limits. However, they are often different from one jurisdiction to another, thereby referring to different integration times or percentile values, giving that this kind of evaluations are hardly comparable from country to country (Nicell, 2009; Jeong 2012).

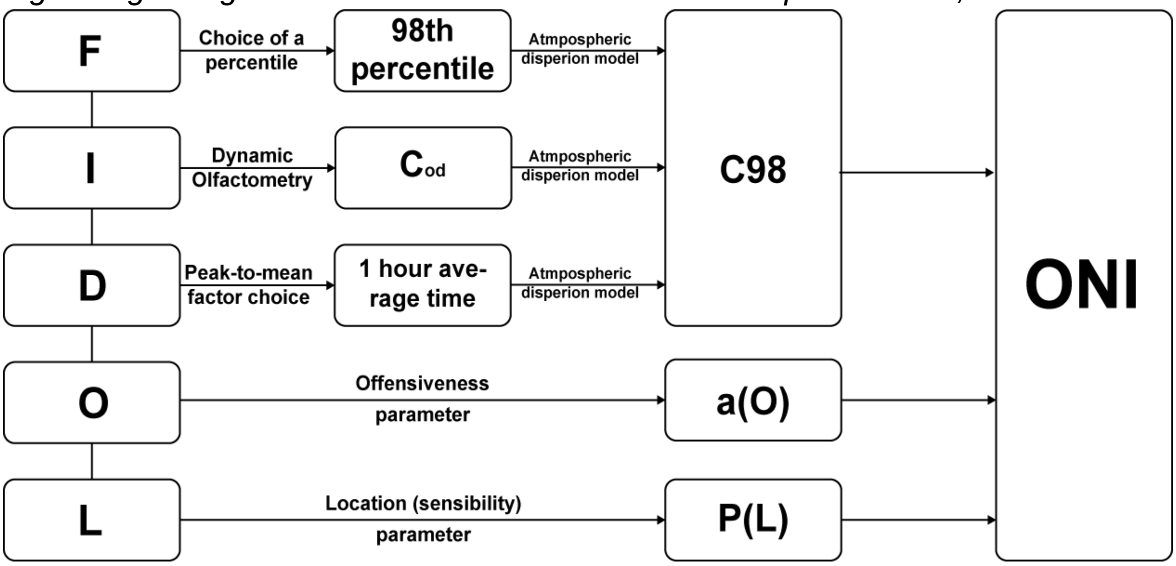
Up to now, odour impact is mostly quantified by means of the above mentioned series of assessments and parameters.

However, as discussed in the Introduction, the five FIDOL parameters play an essential role to define the odour nuisance at a receptor. The above described odour impact assessment approach, based on the application of dispersion modelling, which calculates the frequency of exceedance of an odour concentration value in the area surrounding the source, only accounts for 3 of the 5 factors: frequency, intensity and duration.

As a matter of fact, the choice of the percentile value univocally fixes the frequency of the odour events. The intensity value is linked to the ground odour concentration.

The duration is linked to the software integration time, usually an hour. The duration of the odour event can then be represented by the choice of a fixed peak-to-mean factor F, or by the use of variable factors expressed as functions of different parameters, such as distance from the source or atmospheric stability (Smith, 1973) (Schauberger, et al., 2012).
The above described methods for odour impact assessment by means of the simulation of emission dispersion, is one of the most used, however, it does not consider the remaining two FIDOL parameters: offensiveness and location. This means that odour dispersion modelling cannot be considered as completely exhaustive, as it ignores two fundamental parameters for impact assessment.
De facto various authorities, at local level, already fix different limits for different kind of industries, linked to the expected offensiveness of the emissions, and for different areas, linked to the environmental protection that a territory has been decided to have. For example a rendering or a composting plant has usually more restrictive limits with respect to those given to an industrialbakery or a chocolate industry.
Until now the criteria used to decide stricter or weaker limits, depending on the hedonic tone and the location of the emission, are totally arbitrary and there isn't a unique way to find them out.
Moreover, in some cases, when the emission is considered deeply unpleasant, other methods are used as authorization criteria, like the maximum emission at the source (ONORM S-2205-1, 1997) and the minimum distance from the first houses (JORF, 2005; VROM, 1996). The aim of this paper is to propose an univocal method that considers all the FIDOL parameters (particularly offensiveness and location) that contribute to olfactory nuisance: the international harmonization of the odour assessment method is then possible and desirable, in order to fix homogeneous limits in the regulatory acts.

Fig.2: Logic diagram: from five FIDOL factors to an unique indicator, ONI.



2.2 The "offensiveness" parameter

Numerous studies invite to consider the offensiveness of certain odours (Sucker, et al., 2008; Miedema, et al., 2000)

Already today, in the United Kingdom, different concentration limits at the receptor, for different types of plant and processing, are set, depending on the relative expected offensiveness (UK Environmental Agency, 2011).

Sucker et al. (2008) carried out a comparison among results of a survey through questionnaires, filled out by residents, and a field inspection, where the correlations between the hedonic tone assessments by the panel and by residents were highlighted. In the second part of this study, the impact of hedonic tone on the perception of odour nuisance is again underlined, and a good correlation between frequency and nuisance using a logarithmic scale is also shown.

A subsequent study (Miedema, et al., 2000) tries to investigate a correlation between olfactory nuisance and odour concentration and states a relationship between the percentage of residents who declare to be highly annoyed and the odour concentration at the 98th percentile (C98) obtained by a dispersion model. This analysis was carried out for different installations, characterized by different odour offensiveness. Performing a single generic assessment that includes all the sites, it should be noted that the percentage of people who declare high nuisance is closely related to the C98 through the logarithmic equation:

$$\%\mathrm{HA} = \mathrm{a} \cdot (\mathrm{logC}_{98})^2 \qquad (3)$$

where %HA is the percentage of residents annoyed (considered by Miedema, et al., 1998 upper then 72/100), "a" is a fitting coefficient, "logC_{98}" is the logarithm of the odour concentration at the receptor.

By differentiating the various plants with different degrees of unpleasantness and regressing the curves of Miedema for the calculation of the coefficient "a", very different values can be obtained between a plant and the other. This fact highlights that offensiveness is a key parameter for the definition the odour nuisance.

To quantify the degree of nuisance resulting from an odour emission, it is possible to use the same equation by Miedema and to define, in a preliminary way, an Odour Nuisance Index, ONI (O), that takes into account the odour offensiveness:

$$\mathrm{ONI}'\,(\mathrm{O}) = \mathrm{a}(\mathrm{O}) \cdot (\mathrm{logC}_{98})^2 \qquad (4)$$

In order to obtain an Odour Nuisance Index depending from odour offensiveness, the coefficient "a(O)" has to be fixed. Obviously, the greater the odour unpleasantness, the greater will be the odour nuisance and the corresponding value "a(O)".

The UK Environmental Agency already classifies odour emissions into the three categories, that could be described as pleasant, neutral or unpleasant. The differentiation can be made on the value of the odour hedonic tone, measured by a suitable sensory technique (VDI 3882, 1994). According to the VDI 3882 standard, the quantification of the hedonic tone occurs in a binary way to differentiate pleasant odours, marked with a + sign, from unpleasant ones, marked with a sign -. The concept of neutral odour would therefore apply to hedonic tones that are equal to zero. The proposal of this study is to divide the whole scale of hedonic tone levels (+4 to -4) into three intervals, with similar magnitude, and to define in this way uniquely the multiplication factor "a(O)". The values defined for this coefficient maintain the ratio 1: 2: 4, to recall the English guideline (UK Environmental Agency, 2011). Moreover we considered as standard situation the neutral class of odours, so that should have a unitary coefficient. This ratio is also comparable to those found in the coefficients of concavity regressed from Miedema, et al. 2000.

Tab 1: Proposal for the a(O) values in function of the hedonic tone values

Offensiveness Class	**Hedonic Tone**	**a(O)**
Pleasant odour	From +4 to +1.5	0.5
Neutral odour	From +1.5 to -1.5	1
Unpleasant odour	From -1.5 to -4	2

2.3 Location

Another crucial parameter for the quantification of the odour nuisance is the place where the odour is perceived. This variable is closely linked to the prediction and expectation of the amenity of a certain urban or geographical location.

The degree of discomfort is significantly lower if the odour is perceived in a rural area or in an industrial area compared to the case in which it is perceived in a sensitive area as in the surroundings of a hospital, or in particular places of artistic or historic interest.

Differentiating zones in an urban area thus means giving them a different value that also reflects the economic value of the real estate. Normally the local administration is responsible for providing this differentiation.

For this reason, for the evaluation of the odour nuisance, another parameter that has to be considered for the contextualization of the location parameter is the population density: the odour nuisance, measured as numbers of complaints, will undoubtedly be greater in a highly populated area than in a less populated area. This is because, when analysing not just the odour itself, but rather the nuisance arising from it, the population density indicates how many people can potentially be annoyed. For this reason, also the population density will be proportional to the risk that the complaint effectively occurs.

The proposal for an area differentiation weighing the odour nuisance is not new. Some authors have proposed a method providing different odour concentration limits at the 98th percentile in function of the sensitivity of the receptor (Rossi et al,

2015). In this case, two different hypothetical types of receptor classifications are considered: a classification by area and a classification per building (or unit).
The classification by area is, for sure, the most simple and practical approach. However, there are cases in which it is as important to protect sensitive buildings, or historical/architectural buildings inserted in a rural area.
Considering therefore that what we want to quantify is not the odour itself, but the public nuisance that originates from the presence of an odour (Van Harreveld, 2001), we can consider the odour nuisance as the risk that receptors suffer an odour problem originating from a plant.
The concept of risk quantification (R), already used in safety-related fields, is calculated as the product of the probability (P) of event occurrence and its magnitude (M) (Rota et al., 2007).

$$\mathrm{R = P \cdot M} \qquad (5)$$

This concept can be applied to the specific field of odour nuisance evaluation by considering the risk “R” as the risk of public annoyance-nuisance, the magnitude “M” as a function of frequency, intensity, duration and hedonic tone of the odour events, and the probability “P” as a function of the place linked to quantity of receptors and their expectations.
Using this approach, even in cases in which the magnitude is important, if the odour is present in an uninhabited area, the probability of creating nuisance or complaints will be almost equal to zero (P ~ 0). Similarly, in the case the receptors are located in a densely populated area or are particularly sensitive (in this case P assumes important values), but the odour intensity is very low (M ~ 0), the risk of annoyance would be negligible.
In this way, the equation for the odour nuisance index can be written as:

$$\mathrm{ONI = M(F, I, D, O) \cdot P(L)} \qquad (6)$$

The function M (F, I, D, O), which represents the magnitude, could be represented by the equation (4) previously reported.
The equation that defines the odour nuisance index becomes:

$$\mathrm{ONI = ONI'\,(F, I, D, O) \cdot P(L) = a(O) \cdot (LogC_{98}(F, I, D))^2 \cdot P(L)} \qquad (7)$$

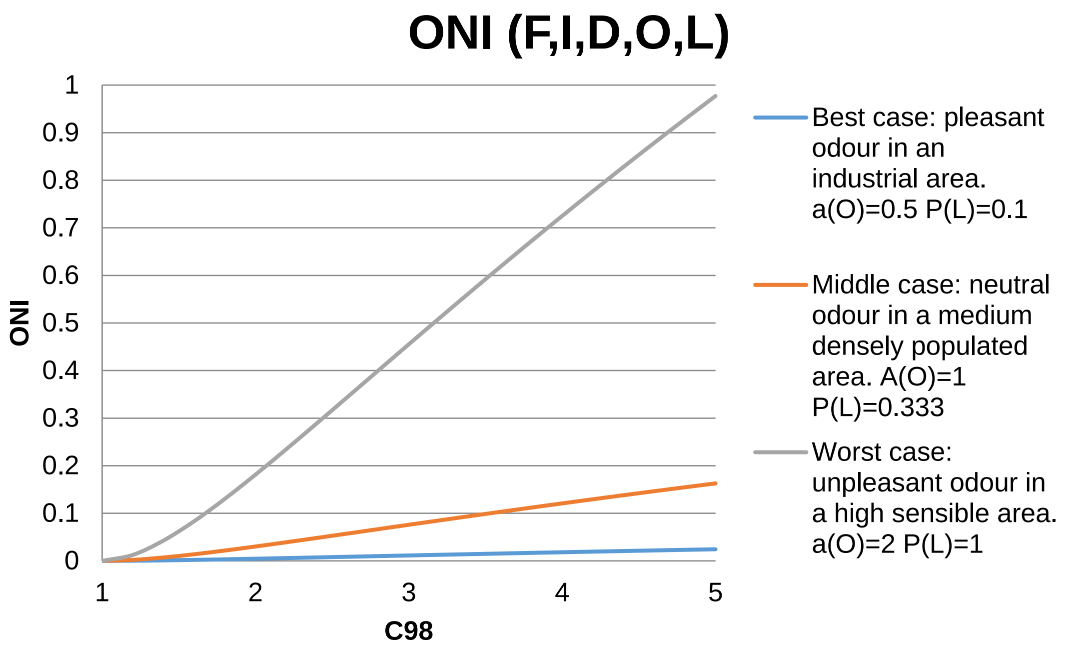
To define P (L) values, the reciprocal data of the odour concentration limits proposed by Rossi et al. 2015 can be used.
In doing that, the coefficient P (L) qualifies a place as the moderating factor; i.e. an area that is considered sensitive and to be preserved can be considered as a standard situation with a unitary coefficient. If an odour is perceived in a different place, then this can only have a minor effect on the receptor.

Tab 2: Proposal for the P(L) values on the function of area sensibility

Sensibility Class	Odour concentration	P(L)
High densely populated areas and areas with very sensitive receptors (hospital, school, churches)	1	1
Medium population density areas	2	0.5
Low population density areas	3	0.333
Areas with scattered houses	4	0.25
Rural and agricultural areas	5	0.2
Exclusively industrial areas	10	0.1

In this way C98 is no more the unique parameter to evaluate the odour nuisance at the receptor, as is possible to see in the figure below:

Fig. 3: Example of three different ONI's trends that show the dependence of the nuisance assessment on offensiveness and location parameters



3. Conclusions

This study outlines a methodological approach which can promote the study and research of methods and models that characterize the odour nuisance.

In this work, a formulation of the equation that includes all FIDOL parameters for the definition of an odour nuisance index is proposed. In this way the subjectivity with witch the odour limits are fixed, for different kinds of industries, can be overtaken.
In the formulation of this expression, in addition to traditional parameters as frequency, intensity (concentration), and duration, we hypothesized, as the initial estimate, some coefficients to be used within the equation considering the hedonic tone a(O) and the localization of the receptor P(L).
As a final result, a proposal is given of how to link these parameters in order to obtain an expression for the Odour Nuisance Index: $\mathrm{ONI} = \mathrm{P(L)} \cdot \mathrm{a(O)} \cdot (\mathrm{LogC}_{98})^2$.

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5. References

Austrian Standards ONORM S 2205-1:1997 04 01, Technische Anforderungen an Kom-postierungsanlagen zur Verarbeitung von mehr als 3000 t pro Jahr – Bioabfall aus Haushalten, Austrian Standards plus GmbH, Wien, Austria.
Brennan, B., 1993. Odour nuisance. Water and waste treatment. 36, 30-33.
Cain W.S., Schiet F.T., Olsson M.J., de Wijk R.A., 1995. Comparison of Models of Odor Interaction. Chemical Senses. 20, 6, 625-637.
Capelli, L., Sironi S., Del Rosso R., Centola P. Bonati S., 2010. Improvement of olfactometric measurement accuracy and repeatability by optimization of panel selection procedures. Water Science & Technology. 2010, 61, 5, 1267-1278
Capelli, L., Sironi S., Del Rosso R., Centola, 2009 Predicting odour emissions from wastewater treatment plants by means of odour emission factors. Water Research. 43, 7. 1977-1985
Capelli L., Sironi S., Del Rosso R., Guillot J.-M., 2013. Measuring odours in the environment vs. dispersion modelling: A review. Atmospheric Environment 79, 731-743
CEN. 2003, 2003. EN 13725:2003. Air quality. Determination of odour concentration by dynamic olfactometry. Brussels.
D.G.R.n.7/12764, 2003. Regione Lombardia. “Linee guida relative alla costruzione e all’esercizio degli impianti di produzione di compost”, Bollettino Ufficiale della Regione Lombardia, Primo supplemento straordinario del 13/05/2003
D.G.Rn.149, 2001. Regione Emilia-Romagna, “Criteri tecnici per la mitigazione degli impatti ambientali nella progettazione e gestione degli impianti a biogas”, Bollettino Ufficiale della Regione Emilia-Romagna, Parte Seconda n. 164 del 09/11/2011
UK Environmental Agency. 2011. Additional guidance for H4 Odour Management.
Freeman, T., Cudmore, R., 2002. Review of Odour Management in New Zealand. Air Quality Technical Report No. 24. Wellington, NZ : New Zealand Ministry of Environment, 2002.

Griffiths, K. D., 2014. Disentangling the frequency and intensity dimensions of nuisance odour, and implications for jurisdictional odour impact criteria. Atmospheric Environment. 90, 125-132.
Hobson, J., 1995. The Odour Potential: A New Tool for Odour Management. Water and Environment Journal. 9, 5, 458-463.
Journal Officiel de la République Française (JORF), 2005. Arrêté du 7 Février 2005 fixant les règles techniques auxquelles doivent satisfaire les élevages de bovins, de volailles et/ou de gibier à plumes et de procs soumis à déclaration au titre du livre V du code de l'environnement, JORF.
Leonardos, G. 1995. Review of odor control regulations in the USA. In Odors, Indoor and Environmental Air, Proceedings of a Specialty Conference of the Air and Waste Management Association, Bloomington, MN. 73-84.
Miedema, H. M., & Vos, H. 1998. Exposure-response relationships for transportation noise. The Journal of the Acoustical Society of America, 104, 6, 3432-3445.
Miedema, H.M.E.,Walpot J.I., Vos H., Steunenberg C.F., 2000. Exposure-annoyance relationships for odour from industrial sources. Atmospheric Environment. 34, 2927-2936.
Mielcarek, P., Rzeźnik, W. 2015. Odor emission factors from livestock production. Polish Journal of Environmental Studies. 24, 1, 27-35.
Nicell, J. A. 2009. Assessment and regulation of odour impacts. Atmospheric Environment. 43, 1, 196–206.
Preti G., Gittelman T. S., Staudte P. B. and Luitweiler P., 1993 Letting the nose lead the way malodorous components in drinking water. Anal. Chem. 65, 699–702.
Rota, R., Nano, G., 2007. Introduzione alla affidabilità e sicurezza nell'industria di processo. Pitagora.
S 2205-1, 1997, Austrian standard, Technische Anforderungen an Kompostierunhsanlagen zur Verarbeitung von mehr als 3000 t pro jahr, Austria.
Piringer, M., & Schauberger, G. 2013. Dispersion modelling for odour exposure assessment. Odour Impact Assessment Handbook, 125-174.
Rossi, A. N., Il Grande, M., Bonati, S. 2015. L'impatto olfattivo delle emissioni in atmosfera: la classificazione dei recettori sensibili. XVII Conferenza nazionale sul compostaggio e la digestione anaerobica. Rimini, Italia.
Schauberger, G., Piringer, M., 2012. Assessment of Separation Distances to Avoid Odour Annoyance: Interaction Between Odour Impact Criteria and Peak-to-Mean Factors. Chemical Engineering Transactions. 30, 13-18.
Sironi S., Capelli L., Centola P., Del Rosso R., Il Grande M., 2005 Odour emission factors for assessment and prediction of Italian MSW landfills odour impact. Atmospheric Environment 39, 5387–5394.
Sironi S., Capelli L., Centola P., Del Rosso R., Il Grande M., 2007. Odour emission factors for assessment and prediction of Italian rendering plants odour impact. Chemical Engineering Journal. 131, 225–231.
Smith, M.E. 1973. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. New York.

Sucker, K., Both R., Bischoff M., Gusky R., Kramer U., Winneke G., 2008. Odor frequency and odor annoyance. Part I: Assessment of frequency, intensity and hedonic tone of environmental odors in the field. International Archives of Occupational and Environmental Health. 81, 6, 671-682.

Sucker, K., Both R., Bischoff M., Gusky R., Kramer U., Winneke G., 2008. Odor frequency and odor annoyance Part II: Dose–response associations and their modification by hedonic tone. International Archives of Occupational and Environmental Health. 81, 6, 683-694.

United States Environmental Protection Agency (US EPA). 1995. Compilation of Air Pollutant Emission Factors. Research Triangle Park, NC, USA Vol. I: Stationary Point and Area Sources.

Van Harreveld A.P., From Odorant Formation to Odour Nuisance: New Definitions for Discussing a Complex Process. Water Science and Technology. 44, 9, 9-15

VDI 3882/Part 2, 1994 Determination of Hedonic Tone VROM, Richtlijn Veehouderij en Stankhinder, 1996. Regulation on livestock farming and stench nuisance.

Watts, P. J., Sweeten, J. M. 1995. Toward a better regulatory model for odour. Proceedings of the Feedlot Waste Management Conference. Queensland, Australia

Wilson, G. E., Schroepfer, T. W., Huang, J. Y. C. 1980. Atmospheric sublayer transport and odor control. Journal of the Environmental Engineering Division. 106, 2, 389-401.