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Recent developments in odour modelling and assessment in five provinces in Austria

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Abstract

It can safely be stated that odour assessment is amongst the least harmonised environmental issues within the European Union. Even on a national level, local authorities sometimes use different approaches. In an effort to harmonise odour assessment in Austria, five provinces—Styria, Salzburg, Carinthia, Burgenland and Vorarlberg—issued a new guideline setting thresholds for odour hour frequencies dependent on the annoyance potential. The limit values were derived from examinations of complaint rates by neighbours of various odour sources and existing exposure–response relationships published in literature. For odours, where no such relationships were available, comprehensive tests using the polarity profile method have been carried out. Unfortunately, the polarity profile method did not provide useful results. Moreover, the corresponding modelling technique for odour hours has been improved, too. Furthermore, odour emission factors from animal husbandry have been investigated by olfactometric measurements and finally been updated, because the emission factors listed in the comprehensive German guideline VDI3894-1 seem not to be representative at least for Austrian conditions.

Keywords Odour · Odour guideline · EN 16,841–1 · GRAL · Odour hour assessment · Concentration variance model

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Introduction

A decade ago, it was still common in Austria to use a rather simple approach relating animal numbers, ventilation types, feeding techniques and wind direction frequencies with separation distances for assessing possible odour annoyance around livestock buildings (Schauberger et al., 1997). On the other hand, in the frame of licencing procedures according to the Austrian trade law, dispersion modelling techniques have already been applied frequently. In the majority of cases, Lagrangian particle models are in use in Austria. With increasing computational power, such models became more and more applicable even for the assessment of—as sometimes considered—small sources/projects such as odour assessment for livestock buildings. In this work, recent improvements regarding the assessment of odour impact in Austria are presented. Besides the issue of new modelling techniques that have been developed, a guideline for assessing odour annoyance has been issued for the first time for the provinces Styria, Salzburg, Carinthia, Burgenland and Vorarlberg. Finally, new odour emission factors have been set up for pig and poultry livestock buildings.

New modelling techniques

In Austria, odour assessment is based on so-called odour hours defined by at least 6 min of perceivable odour concentrations. According to VDI 3788 (2000), the correct calculation of odour hours is carried out by taking into account the individual odour sensitivity of qualified panel members, which is usually approximated by a log-normal distribution (Janicke and Janicke, 2004)

$$P_0(c) = 0.5[1 + \mathrm{erf}(\frac{\ln({}^{c}/_{c_{OT}})}{\sqrt{2}\alpha})] \quad (1)$$

with erf being the error function, c the odour concentration, c_{OT} the odour concentration detected by 50% of qualified panel members and α a scale parameter. Hence, $P_0(c)$ describes the fraction of qualified panel members that are able to detect a certain odour concentration. In this way, an odour hour can be defined more precisely by

$$\kappa = \int_0^\infty P_0(c)f(c)dc \quad (2)$$

whereby $f(c)$ is the probability density function of odour concentrations at some point observed during 1 h. An odour hour is defined by $\kappa \geq 0.1$, i.e. in 10% of the time odour would be detected by qualified panellists. One may define c_{OH} as the odour concentration threshold that just triggers an odour hour defined in this way.

While modelling $f(c)$ is still a matter of research (e.g. Ferrero et al., 2020), specifically for odour assessments for regulatory purposes most models calculating odour hours aim at determining the 90th percentile of the cumulative frequency distribution of odour concentrations of an hour. Often the 90th percentile is normalised by the hourly mean concentration by defining

$$R_{90} = C_{90}/\overline{C} \quad (3)$$

where C is the hourly mean concentration, and C_{90} the 90th percentile. In Germany, the regulatory odour dispersion model AUSTAL2000G (GIRL, 2009) uses the simple relationship $R_{90} = 4.0$, which is based on the work of Janicke and Janicke (2004). This assumption has been broadly used in Austria, too. The advantages are its robustness, and its tendency to provide a conservative estimate for R_{90}, which is generally desirable when applying (simple) models for regulatory purposes. As pointed out by Janicke and Janicke (2004) and Oettl et al. (2018a), using $R_{90} = 4.0$ is a rather good estimate as long as the value of α in Eq. (1) is larger than approximately 1.0. However, as shown by Oettl et al. (2018a), the function of $f(c)$ becomes more important for the determination of an odour hour for smaller values. Table 1 lists calculated values for the ratio $c_{OH}/\overline{C}$ for three different values for α. Two different Weibull probability density functions have been assumed for $f(c)$: (i) a homogenous concentration distribution representing conditions in the far field from an odour source (almost uniform concentration distribution), and (ii) an exponential concentration distribution that is representative for conditions closer to a source. It can clearly be seen that $c_{OH}/\overline{C}$ is almost independent of $f(c)$ when α is equal or larger than 1, while the influence of $f(c)$ on $c_{OH}/\overline{C}$ increases with decreasing α.

The value of α can be determined by dynamic olfactometry (EN 13,725, 2003) for any kind of odour. By the courtesy of the municipality of Linz (Binder, 2017), a large dataset comprising 1350 α-values, determined by olfactometric measurements for different kinds of odours (Fig. 1), has been made available to the authors. The values are significantly lower than 1.0 and little variability amongst the different odours was found suggesting that $f(c)$ is important for the assessment of odour hours. Computing $f(c)$ requires dispersion models that are capable of simulating odour concentration fluctuations (Ferrero et al., 2019).

Recently, Oettl and Ferrero (2017) developed a new method for calculating R_{90}, which is based on a simplified advection–diffusion equation (e.g. Manor, 2014) for the concentration variance $\overline{c^2}$:

$$\frac{\partial \overline{c^2}}{\partial t} = 2\sigma_{ui}^2 T_{Li}\left(\frac{\partial \overline{C}}{\partial x_i}\right)^2 - \frac{\overline{c^2}}{t_d} \quad (4)$$

T_{Li} are the Lagrangian integral time scales, σ_{ui}^2 is the wind-velocity variances in each direction, and t_d is the dissipation time scale characteristic for the decay of the concentration variance. In contrast to the German approach of using a constant R_{90}, the method provides spatially inhomogeneous values for R_{90}, which depend strongly on the three-dimensional structure of the computed hourly mean odour concentrations. Therefore, source geometries as well as mean wind and turbulence fields have a strong impact on

Table 1 Ratios for $c_{OH}/\overline{C}$ triggering an odour hour according to Eq. (2) for two different Weibull distributions for $c_{OH}/\overline{C}$. The different values for α correspond to the ability of qualified panellists to detect a specific odorant according to Eq. (1)

	$c_{OH}/\overline{C}$		
$f(c)$	α = 0.3	α = 0.6	α = 1.0
Very homogenous concentration distribution (shape parameter k = 5)	1.6	2.2	3.6
Exponential concentration distribution (shape parameter k = 1)	2.6	3.0	4.0

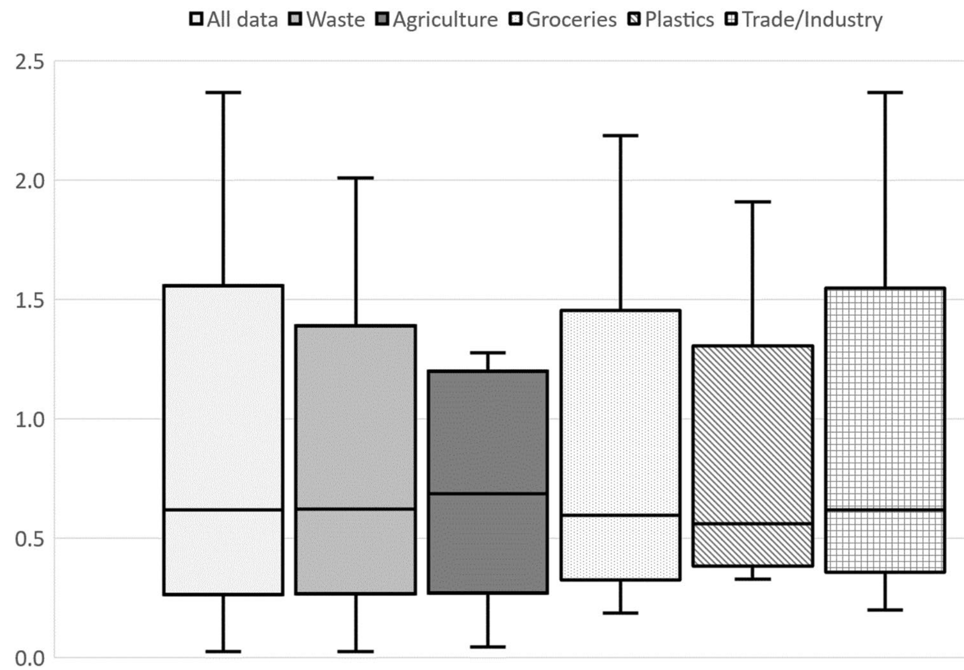

Fig. 1 Box plots of measured α-values (Binder, 2017) by dynamic olfactometry (EN 13,725, 2003) for different odours

computed R_{90}. Still, the proper determination of t_d is a matter of research, which has been addressed in a recent work by Ferrero and Oettl (2019). However, the development of a universal function for t_d that could be applied for all different kinds of sources is still to be done. The method has been implemented in the Lagrangian particle model GRAL (Oettl, 2019) and has been tested using the Uttenweiler and Joint Urban 2003 experiments (Oettl and Ferrero, 2017). A total of 14 tracer releases from a single stack of a pig shed have been carried out in Uttenweiler, Germany (Bächlin et al., 2003). The Joint Urban 2003 field study took place in downtown Oklahoma City, USA (Clawson et al., 2005). Fast-response gas analysers were in operation during ten intensive observation periods at varying distances between a few hundred up to 800 m from each tracer release. A slight tendency for overestimating R_{90} was found by Oettl and Ferrero (2017), which was confirmed by Brancher et al. (2020), who implemented the method in the Lagrangian particle model LASAT and used the Uttenweiler experiments in their evaluation, too. Both studies conclude that the new methodology outperforms existing approaches for calculating R_{90}.

In addition to testing the method's capability for computing R_{90}, Oettl et al. (2018a) demonstrated that computed odour hour frequencies using GRAL in the vicinity of a pig shed agreed well with observed frequencies based on the recently issued EN 16,841–1 (2017). It should be emphasised that the main advantage of using odour hours in assessment studies over the widely used limit values based on percentiles of hourly mean odour concentrations (e.g. Brancher et al. 2017) is the possibility of using either dispersion modelling or field inspections in the assessment, respectively. Therefore, the new odour guideline presented in the next chapter proposes odour impact criteria based on odour hour frequencies.

Development of a new odour guideline

Austrian laws do not stipulate that any odour nuisance is to be prevented, but only unacceptable nuisance. However, the term 'unacceptable' is not a scientific or medical term and, thus, requires further consideration. Until recently, no guideline was available in Austria addressing this topic.

In their remarkable review, Brancher et al. (2017) investigated odour impact criteria of 28 countries across the world. Five main approaches used in jurisdictions were identified: (1) maximum-impact standard, (2) separation-distance standard, (3) maximum-emission standard, (4) maximum-annoyance standard and (5) technology standard. The most commonly used approach is the maximum-impact standard with the application of odour concentration limits in ambient air. However, Brancher et al. (2017) report a wide range of thresholds, percentiles and peak-to-mean factors used in different countries demonstrating the current lack of harmonisation. This is also true for Austria, where even within some federal states different odour impact criteria are in use. Some provinces in Austria prefer the usage of the odour standards established in Germany as defined in the GIRL (2008), while others make use of thresholds issued in an outdated report in Austria (OAW, 1994). Though it is strongly felt that national harmonisation is needed, Austrian experts in the field of odour assessment could not yet agree on common standards. Meanwhile, the provinces of Styria, Salzburg, Carinthia, Burgenland and Vorarlberg agreed on establishing a common guideline (Oettl et al., 2018b).

The guideline takes advantage of many well-established items of the German GIRL (2008) regulation. For instance, the regulation about the required assessment domain for dispersion modelling has been taken from the GIRL without any major changes. When the GIRL was issued for the first time in Nordrhein-Westfalen, Germany, in 1986, the hedonic tone of odours was practically not considered. Later, backed by the study of Sucker et al. (2008), the GIRL was revised and included so-called animal-specific factors to account for the different hedonic tones of odours stemming from pigs, broilers and cattle. Furthermore, disgusting odours have been recognized as requiring a special treatment, though there is still no defined method provided by the GIRL.

Weitensfelder et al. (2019) and Moshammer et al. (2019) analysed resident complaints near various odour sources (livestock buildings, compost facilities) by means of dispersion modelling using the Lagrangian particle model GRAL. Resulting exposure–response relationships impressively showed a strong influence of the hedonic tone on complaint rates. Furthermore, various predictors for odour annoyance have been compared with regard to their ability to explain existing complaint rates. It was found that using a threshold of 1 odour unit per m^3 in dispersion modelling and using annual odour frequencies is a method very well suited for explaining odour complaints, thus confirming the German GIRL, which fundamentally uses the very same method.

It is important to note that Weitensfelder et al. (2019) used emission factors for animal husbandry as reported in the German VDI 3894–1 (2011), while Moshammer et al. (2019) already used updated emission factors as described in "New emission factors for animal husbandry". As will be outlined later, in particular the emission factors for pig and chicken fattening according to VDI 3894–1 (2011) were found too low compared with our own observations (e.g. Oettl et al., 2018a) and emission factors reported in literature. Hence, the corresponding exposure–response relationships depicted in Weitensfelder et al. (2019) are deemed not as representative as those presented in Moshammer et al. (2019).

Figures 2 and 3 illustrate exposure–response relationships for various odours as found in literature and obtained from our own data (Moshammer et al., 2019). For very annoying odours (compost facilities), the curve is rather steep, calling for a very strict threshold. Furthermore, Sucker et al. (2006) found hardly any relationship between odour hour frequencies and complaint rates for cattle odours. Interestingly, the curves for chicken odours obtained by Sucker et al. (2006) and our data are practically similar, although the methods for deriving the relationships differ significantly. Instead of using dispersion modelling as technique for obtaining odour hour frequencies at resident's addresses, Sucker et al. (2006) used field inspections as proposed in the VDI 3940–1 (2006). Moreover, Sucker et al. (2006) calculated complaint rates based on a questionnaire, while Moshammer et al. (2019) used primarily complaint data gathered by the administration of Styria over the past years.

For pig odours, several studies were found in literature for comparison purposes. The relationship between odour hour frequency and complaint rates obtained in this work is very similar to what was found in a study by Noordegraf and Bongers (2007), who used dispersion modelling, too. It

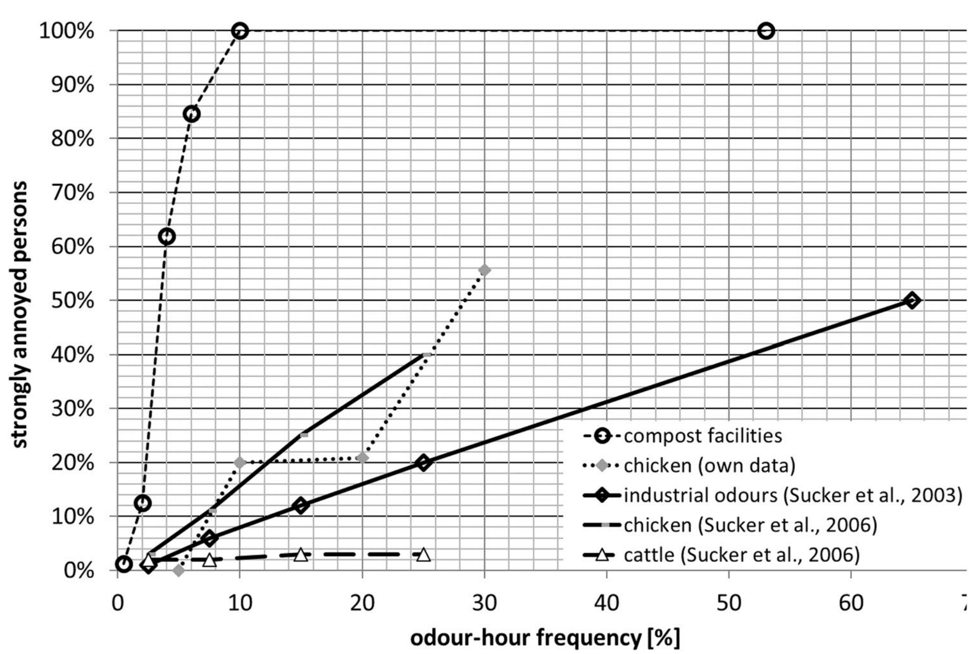

Fig. 2 Exposure-response relationships for different odours based on own data and literature

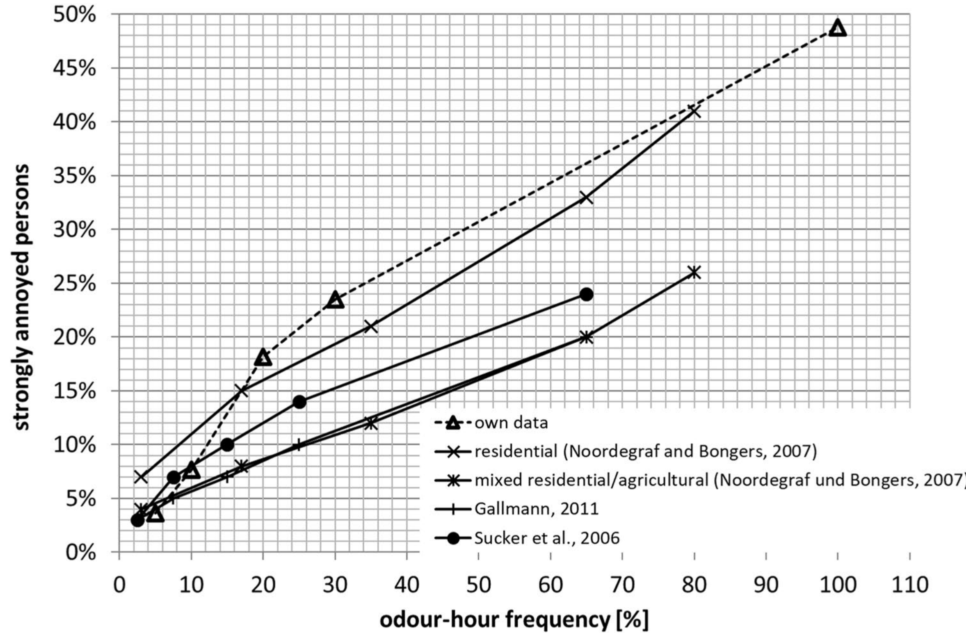

Fig. 3 Exposure–response relatsssionships for pig odour based on own data and literature

Table 2 Recommended impact criteria for odour hour frequencies for agricultural odours

Annoyance potential	*Examples*	*Pure residential, sensitive areas*	*Mixed agricultural/residential*	*Industrial, less sensitive areas*
Low	Cattle, horses, alpacas, sheep, goats, biofilters, silages	40%	-	-
Medium	Pigs	15%	20%	30%
High	Chicken	10%	15%	20%

should be stressed that Noordegraf and Bongers (2007) used the 98th percentile of hourly mean odour concentrations of a whole year. Based on GRAL simulations for a fictitious shed and by comparing resulting odour hour frequencies with corresponding 98th percentiles, a relationship amongst these two measures was obtained and used to render the data of Noordegraf and Bongers (2007) into odour hour frequencies. Though this method introduces quite some uncertainty, the relationships found by Noordegraf and Bongers (2007) seem to fit very well within the German studies (Gallmann, 2011; Sucker et al., 2006) and our data. It can be seen that complaint rates depend on the character of the residential areas. In mixed agricultural/residential areas, people seem to feel less annoyed by pig odours compared to locals living in pure residential areas.

Based on these exposure–response relationships, various threshold values have been established as listed in Tables 2 and 3. Basically, the chosen impact criteria cannot be deduced in a scientifically rigorous manner mainly for two reasons: (i) only few exposure–response relationships exist, and these are limited to a few types of odours. As can be seen from Fig. 3, even exposure–response relationships for the same odour do not overlap but suggest a certain range of strongly annoyed people for a given level of odour hours. (ii) Austrian laws require that any kind of acceptability criteria has to be set up for a 'healthy, normal sensitive person'. Having said this, one could reason the chosen impact criteria in the following way: Assuming that the sensitivity of people follows a normal distribution, 'normal' could be defined by the number of people within the standard deviation, which would correspond to 68% of the population. The remaining 32% would then be classified as being not 'normal sensitive'. Half of them are 'not normal' in terms of a very low

Table 3 Recommended impact criteria for odour hour frequencies for non-agricultural odours

Annoyance potential	*Examples*	
Low	Biofilters	40%
Medium	Domestic heating, oil mills, breweries	15%
High	'Chemical' odours like bitumen, VOCs	10%
Very high	Odours from decay, rot, compost works without treatments, tanneries	2%

sensitivity, and the other part would be termed as highly sensitive. Thus, limit values should then be set around a value of 16% of strongly annoyed persons using exposure–response relationships.

One of the main differences compared with the German guideline GIRL is the introduction of the so-called annoyance potential of odours (hedonic tone), which is thought to be crucial given the distinctive exposure–response relationships for the various odours investigated. Using the very same odour impact criteria for all industrial odours as prescribed in the GIRL seems not appropriate.

It is evident from the existing studies—relating odour hour frequencies to complaint rates—that exposure–response relationships are only available for a very limited number of odours. Consequently, for most odours the so-called annoyance potential has to be determined and compared with the one from odours where exposure–response relationships exist. In "Assessment of the annoyance potential using the polarity profile method", a candidate method for assessing the annoyance potential will be discussed in more detail.

It should be noted that solely for agricultural odours impact criteria depend on land use, which can be argued by the study of Noordegraf and Bongers (2007). Similar investigations for any other kinds of odours are not currently available; therefore, land use is not taken into account for non-agricultural odours.

The impact criteria for odours with a very high annoyance potential (2% odour hour frequency) have been a much-discussed, quite controversial issue in Austria. Nevertheless, it is interesting to note that in Quebec (Canada) a similar threshold is in place (Brancher et al. 2017).

One of the few drawbacks of odour impact criteria based upon odour hour frequencies is the fact that these are to be assessed for a full year. Consequently, odour sources emitting just seasonally or only for a few weeks per year are likely to be underestimated with regard to their odour impact. It should be stressed that field inspections according to EN 16,841–1 (2017) are not meaningful as soon as the expected frequencies of odour hours are low, due to the large sampling error involved. There is a need to establish odour impact criteria for discontinuous sources that can be assessed either by dispersion models or by field inspections. Contrary to the criteria used for continuous sources, where the maximum permitted odour hour frequency varies but the odour concentration at the 90th percentile is constant (1 OU/m^3), for discontinuous sources the maximum allowed odour hour frequency is limited to 2% per year but the odour concentration at the 90th percentile is variable according to the annoyance potential of odours (Table 4). Setting the limit for the odour hour frequencies to a low value ensures that the criteria cannot easily be met due to the reduced emission times of discontinuous sources. These are defined in the new guideline as sources emitting in less than 40% of the year, while continuous sources are those who emit in more than 60% of the year. Sources in between 40 and 60% need to be judged upon both the impact criteria for continuous and discontinuous sources.

Table 4 Recommended impact criteria for discontinuously released odours from non-agricultural sources: 2% odour hour frequency evaluated for the listed odour concentration thresholds

Annoyance potential	*Examples*	
Low	Biofilters	15 OU/m^3
Medium	Domestic heating, oil mills, breweries	5 OU/m^3
High	'Chemical' odours like bitumen, VOCs	4 OU/m^3
Very high	Odours from decay, rot, compost works without treatments, tanneries	1 OU/m^3

Assessment of the annoyance potential using the polarity profile method

It has already been outlined that the number of exposure–response studies that form the basis for establishing odour impact criteria is limited to a few kinds of odours. Based on the collective experience of the experts involved in the development of the new guideline for Styria, Salzburg, Burgenland and Vorarlberg, annoyance potentials have been fixed; for most odours, one has to deal with in licencing procedures. However, for any other odour there is still a need for determining the annoyance potential.

A candidate method was thought to be the polarity profile approach (e.g. Sucker and Hangartner, 2012). The use of polarity profiles for odour assessment in ambient air is regulated in a German VDI guideline (VDI 3940–4, 2010): Trained panel members assess the hedonic quality of odours based on 29 polar adjectives (e.g. 'harmonious-disharmonious') using a 7-point rating scale. At the beginning of the procedure, panel members are asked to imagine a perfect smell and perfect stench, respectively. For both, the polarity profile needs to be established first. The VDI 3940–4 defines certain criteria that panel members are required to fulfil when accessing the imaginary smell and stench; otherwise, they have to be excluded from further testing. Finally, the actual type of odour in consideration is correlated with the profiles for smell and stench.

In the context of annoyance, the polarity profile method has already been used successfully (e.g. Sucker et al., 2003). As opposed to a rating scheme based simply on pleasantness vs. unpleasantness of odours, three basic dimensions prevail in the semantic room: evaluation (pleasantness), potency (strength) and activity (arousal). The polar adjectives used in the semantic differential can be either pure or more oblique in representing one or several of the basic dimensions (e.g. Dalton et al., 2008), but either way a polarity profile provides a more detailed definition than 'just' hedonic quality.

Stoll (2019) demonstrated that the annoyance potential of odours from goats and sheep is similar to that from cattle, but less offensive compared to odours from broilers or swine. In a similar work, Winkler (2017) successfully evaluated the offensiveness of odours from horses and fattening bulls using polarity profiles.

In this work, more than 200 polarity profiles were evaluated for several types of odours in order to assess the capability of the method to objectively classify the annoyance potential. The panel members were tested and selected by both EN 13,725 (2003) and VDI 3940–4 (2019). In a first experiment, odours were collected close to the sources using a vacuum pump and Tedlar sampling bags. The odours were then presented to the panel members in an odourless office, where the corresponding polarity profiles were filled out. In a second attempt, the panel members were asked to fill out the polarity profiles in situ in the field at varying distances to the odour sources. Finally, in a third study collected odours were presented to the panel members by means of an olfactometer and the polarity profiles were filled out as soon as an odour could be identified by a panel member. The three different experimental layouts ensured that odours were rated by the panel members at different concentration levels and in different environments (i.e. the odour sources were either visible or not).

An example of polarity profiles for cattle, chicken and pigs is illustrated in Fig. 4. For these three different kinds of odours, rather well-established exposure–response relationships exist (e.g. Figs. 2 and 3). According to these, the annoyance potential is quite different with chicken being the most offensive, followed by pigs, and cattle the least offensive odour. As can be seen from Fig. 4, the polarity profiles for these three odours are quite similar, specifically those for pigs and chicken. Thus, the method does not provide a specification of odours similar to the exposure–response relationships, though all three odours were rated as stench rather than smell by the panel members. The profiles for a representative smell and stench according to the VDI 3940–4 are included in Fig. 4, too. These can be used to calculate the correlation between the profile of the odour under investigation and the representative ones for smell and stench.

Figure 5 shows the correlation coefficients between the profiles for various odours with the ones for the representative smell and stench. The correlations are basically quite reasonable as odours that would usually be acknowledged as smell by the public are indeed positively correlated with the representative smell defined by the VDI 3940–4, and odours that would typically be termed stench by the public are positively correlated with the representative stench. However, the correlation factors between very annoying odours such as animal cadaver and less annoying odours like pig slurry are hardly varying according to the polarity profile method. Presenting odours at different concentration levels and in different environments to the panel members neither improved results. Therefore,

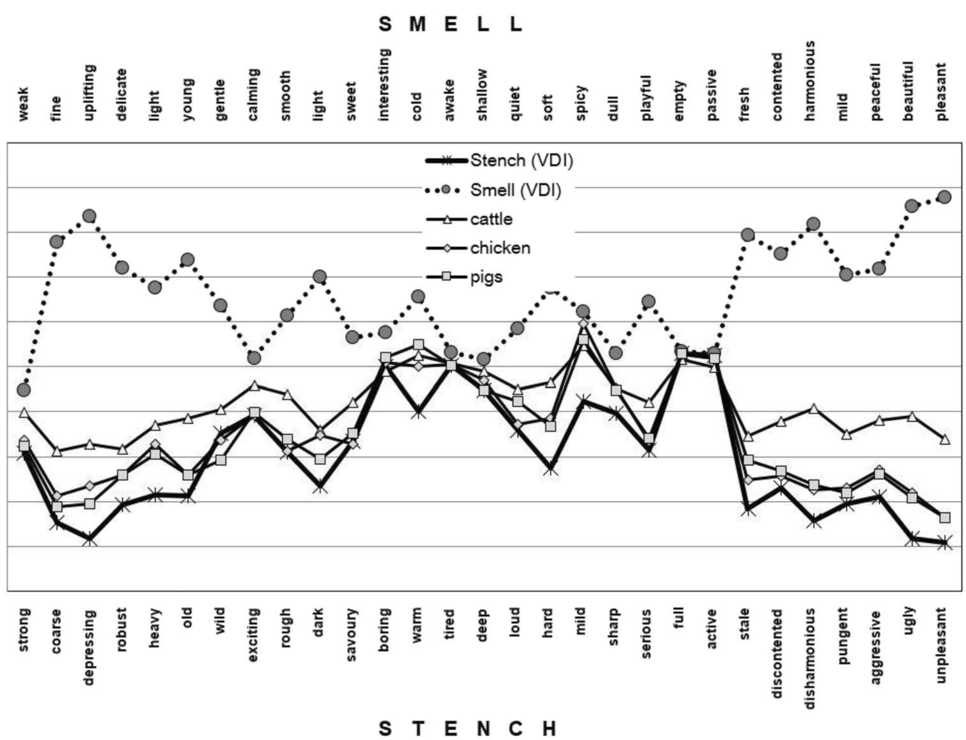

Fig. 4 Polarity profiles for the subjective rating of cattle, chicken, pigs and representative smell and stench

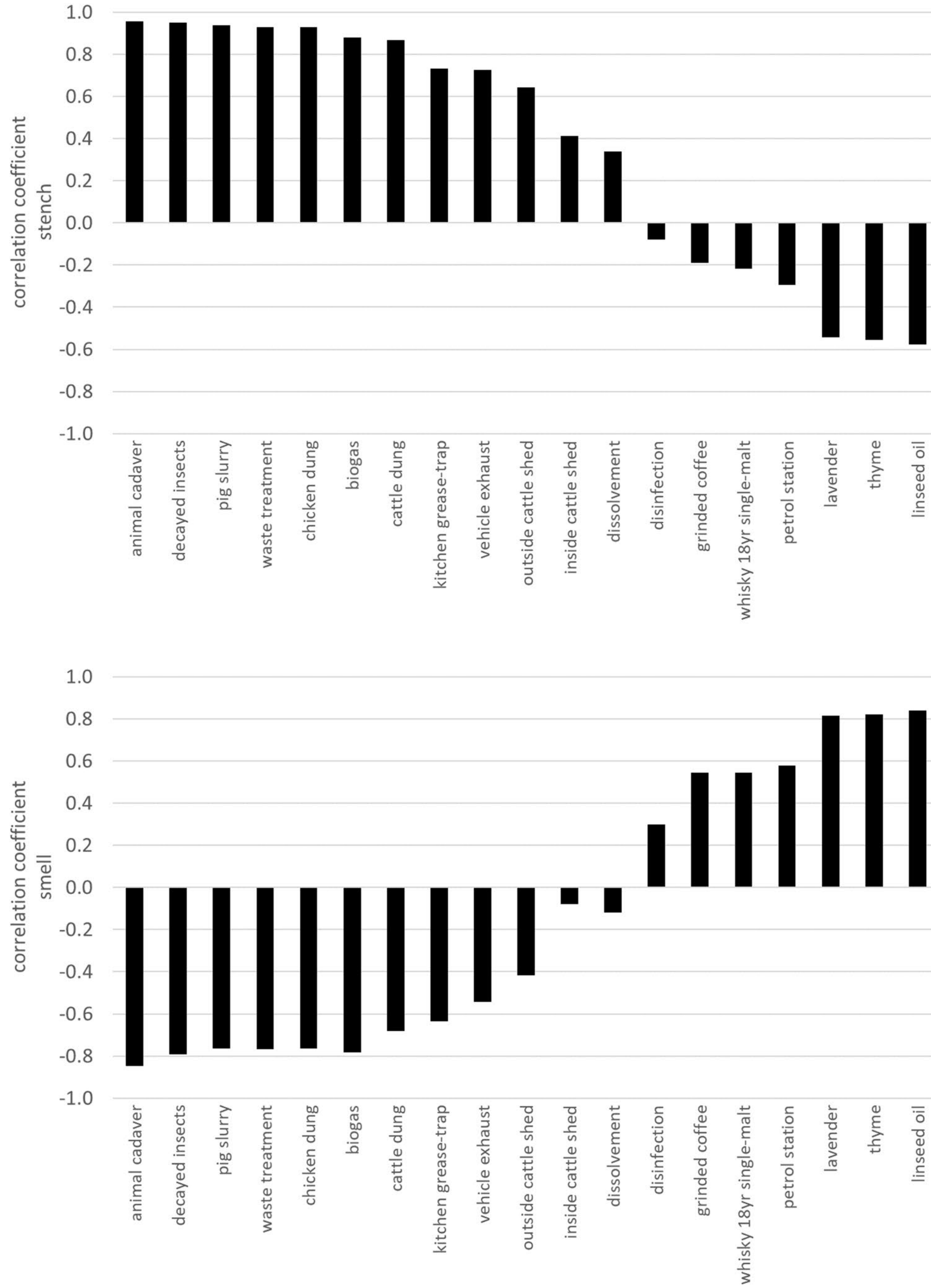

Fig. 5 Correlation of various types of odours with stench and smell using the polarity profile approach according to the VDI 3940–4 (2010)

the VDI 3940–4 is currently not recommended by the odour guideline of Styria, Salzburg, Burgenland and Vorarlberg as a method for objectively determining the annoyance potential, and expert judging still remains the single applicable way.

New emission factors for animal husbandry

A different topic but strongly related with the assessment of odours is the selection of proper emission factors for dispersion modelling—the preferred method of odour assessment in Austria. The most frequent odour assessment studies in Styria concern animal husbandry. For several years, emission factors as proposed by the German guideline VDI 3894–1 (2009) were in use, as it provides a large number of emission factors for different animal categories, types of feeding and litter management. The factors were thought to represent rather an upper limit than realistic odour emissions for modern animal sheds. Due to the tendency of growing animal numbers at farms in Austria, getting permits becomes more and more difficult. Therefore, a few measurement campaigns were initiated in

Table 5 Recommended emission factors for pig and poultry husbandry in Styria, Austria

Animal	Emission factor [OU/s/500 kg]
Fattening pigs	140
Sows	50
Piglets < 25 kg	200
Laying chicken	100
Fattening chicken	200

order to get an idea about how much modern sheds, using some of the latest feeding and housing technologies (e.g. protein-reduced feeding, floor heating), emit compared with the rather old emission factors listed in VDI 3894–1.

In the course of those measurements at livestock buildings (e.g. Oettl et al., 2018a), it became evident that the emission factors provided by the VDI 3894–1 rather tend to underestimate emissions than providing a conservative estimate. A subsequent literature survey indicated that emission factors reported in other European countries apparently disagree with the VDI 3894–1, too (e.g. Hayes et al., 2006; Hill et al., 2014; Mielcarek and Rzeznik, 2015; Ogink and Lens, 2001; Santonja et al., 2017). To avoid an underestimation of the odour impact in the vicinity of livestock buildings, it was decided to establish a new list of recommended emission factors, given that a sufficiently large number of observations or literature data were available (Oettl et al., 2018c). This was the case for pig and chicken husbandry (Table 5). In addition, reduction factors have been defined for various mitigation techniques such as protein-reduced feeding (Table 6) based on literature and own observations (e.g. Le et al., 2007; Loussouarn et al., 2014).

Conclusions

While for many airborne pollutants regulations have been in place for a long time, and standards have been harmonised within the European Union, odour is still neglected even though it can be a strong stressor for people affected by annoying odours. Efforts for establishing odour impact criteria on a national or sub-national level are hindered due to the fact that studies relating certain odour impact criteria with annoyance are still few in number. It should be mentioned that exposure–response studies are usually quite difficult to obtain, as complaints by neighbours living near odour sources are needed as input. On a national level, the number of exploitable complaints concerning a particular kind of odour is often too small for establishing meaningful relationships; thus, it is highly recommended to fund such projects on a European level.

A second topic that would need more attention is the establishment of emission factors for a wide range of odour sources. Increasing the number of measurements, which are often technically challenging, would make odour assessments by means of dispersion modelling more reliable. It should be emphasised that—unlike for most airborne pollutants—erroneous model results concerning odour impact are quickly recognized as such by concerned citizens. This may not only lead to distrusting simulation tools, but sometimes in raising doubts about the neutrality of the local authority in general.

Table 6 Recommended reduction factors for several mitigation techniques

Animal	Mitigation technique	Reduction
Fattening pigs	Protein-reduced feeding (two phases)	0.9
Fattening pigs	Protein-reduced feeding (three and more phases)	0.8
Fattening pigs	Reduced slurry area below slots	0.7
Fattening pigs	Slurry cooling	0.7
Fattening pigs	Open sheds	0.8
Fattening pigs	Closed shed, no slots, natural ventilation via windows	0.5
Fattening pigs	Closed shed, slots, natural ventilation via windows	1.0
Fattening pigs	Separation of excrements and urine	0.25
Fattening pigs and sows	Cool pads	0.9
Fatting chicken	Protein-reduced feeding (three and more phases)	0.8
Fatting chicken	Open sheds, winter garden	0.8
Fatting pigs/chicken	Tested feed additives	0.75

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed Dietmar Oettl, Enrico Ferrero, Hanns Moshammer, Lisbeth Weitensfelder, Michael Kropsch and Michael Mandl. The first draft of the manuscript was written by Dietmar Oettl and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The datasets generated during the current study are not publicly available as annoyance data gathered from individuals formed the basis for the analysis of the dose–response relationships, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval This is an observational study not needing ethical approval.

Consent to participate Informed consent was obtained from all individual participants in the study.

Consent for publication The manuscript does not contain any individual person's data.

Competing interests The authors declare no competing interests.

References

Bächlin W, Rühling A, Lohmeyer A (2003) Bereitstellung von Validierungsdaten für Geruchsausbreitungsmodelle – Naturmessungen. Ingenieurbüro Lohmeyer, Karlsruhe, Germany, 187pp (URL last accessed 11/07/16 : http://www.lohmeyer.de/de/system/files/content/download/publikationen/1408bericht.pdf)

Binder G (2017) Provision of olfactometric measurements. Personal communication. Municipality of Linz, Austria

Brancher M, Griffiths KD, Franco D, Melo Lisboa H (2017) A review of odour impact criteria in selected countries around the world. Chemosphere 168:1531–1570

Brancher M, Hieden A, Baumann-Stanzer K, Schauberger Gü, Piringer M (2020) Performance evaluation of approaches to predict subhourly peak odour concentrations. Atmos Environ: X. https://doi.org/10.1016/j.aeaoa.2020.100076

Clawson KL, Carter RG, Lacroix DJ, Biltoft CA, Hukari NF, Johnson RC, Rich JD, Beard SA, Strong T (2005) Joint Urban 2003 (JU03) atmospheric tracer field tests. NOAA Technical Memorandum OAR ARL-254, 238 pp

Dalton P, Maute C, Oshida A, Hikichi S, Izumi Y (2008) The use of semantic differential scaling to define the multi-dimensional representation of odors. J Sens Stud 23:485–497. https://doi.org/10.1111/j.1745-459X.2008.00167.x

EN 13725 (2003) Air quality – determination of odour concentration by dynamic olfactometry. 71 pp

EN 16841–1 (2017) Ambient air – determination of odour in ambient air by using field inspection – Part 1: Grid method. Draft version. 60 pp

Ferrero E, Manor A, Mortarini L, Oettl D (2020) Concentration fluctuations and odour dispersion in Lagrangian models. Atmosphere 11(1):27. https://doi.org/10.3390/atmos11010027

Ferrero E, Oettl D (2019) An evaluation of a Lagrangian stochastic model for the assessment of odours. Atmos Environ 206:237–246

Santonja GG, Georgitzikis K, Scalet BM, Montobbio P, Roudier S, Sancho LD (2017) Best Available Techniques (BAT) Reference Document for the intensive rearing of poultry or pigs; EUR 28674 EN; https://doi.org/10.2760/020485

GIRL (2009) Feststellung und Beurteilung von Geruchsimmissionen (Geruchsimmissions-Richtlinie – GIRL) in der Fassung vom 5. November 2009 mit Begründung und Auslegungshinweisen, Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz Nordrhein-Westfalen, Düsseldorf, 37 pp

Hayes ET, Curran Th, Dodd VA (2006) Odour and ammonia emissions from intensive poultry units in Ireland. Biores Technol 97:933–939

Hill R, Bealey B, Johnson C, Ball A, Simpson K, Smith A, Theobald M, Braban Ch, Magaz I, Curran T (2014) Scail – agriculture update. Sniffer ER26: Final Report. 162 pp

Janicke L, Janicke U (2004) Development of the dispersion model AUSTAL2000G. Berichte zur Umweltphysik, 5, Ingenieurbüro Janicke, Dunum, 122 pp (URL last accessed 11/07/16: http://www.janicke.de/data/bzu/bzu-005-02.pdf)

Le PD, Aarnink AJA, Jongloed AW, Van der Peet-Schwering CMC, Ogink NWM, Verstegen MWA (2007) Effects of dietary crude protein level on odour from pig manure. Animal 1:734–744

Loussouarn A, Lagadec S, Robin P, Hassouna M (2014) V-shaped scraper: environmental and technical assessment for seven years in the Guernévez experimental farm. Journées Recherche Porcine 46:199–204

Manor A (2014) A stochastic single particle Lagrangian model for the concentration fluctuation in a plume dispersing inside an urban canopy. Boundary-Layer Meteorol 150:327–340

Mielcarek P, Rzeznik W (2015) Odor emission factors from livestock production. Pol J Environ Stud 24:27–35

Moshammer H, Oettl D, Mandl M, Kropsch M, Weitensfelder L (2019) Comparing annoyance potency assessments for odours from different livestock animals. Atmosphere, 10, in print

Noordegraaf D, und Bongers M (2007) Relatie tussen geurimmissie en geurhinder in de intensive veehouderlj. Rapportnummer VROM07A3, April 2007, Opdrachtgewer Ministerie VROM, Den Haag, Niderland; Opdrachtnemer PRA Odournet, Amsterdam, Niederlande, 41 pp

OAW (1994) Umweltwissenschaftliche Grundlagen und Zielsetzungen im Rahmen des Nationalen Umweltplans für die Bereiche Klima, Luft, Geruch und Lärm. In: Österreichische Akademie der Wissenschaften (Ed.), Kommission für Reinhaltung der Luft, Bundesministerium für Umwelt, Jugend und Familie, Vienna. Schriftenreihe der Sektion I, Band 17

Oettl D (2019) Documentation of the Lagrangian particle model GRAL (Graz Lagrangian Model) Vs. 19.1. Amt d. Stmk. Landesregierung, ABT15, Referat Luftreinhaltung, 208 pp (accessible via: http://lampz.tugraz.at/~gral/)

Oettl D, Ferrero E (2017) A simple model to assess odour hours for regulatory purposes. Atmos Environ 155:162–173

Oettl D, Moshammer H, Mandl M, Weitensfelder L (2018b) Richtlinie zur Beurteilung von Geruchsimmissionen. Amt d. Stmk. Landesregierung, Report Nr. LU-08–18, 24 pp http://app.luis.steiermark.at/berichte/Download/Fachberichte/Lu_08_2018_Geruchsrichtlinie_Stmk_C.pdf

Oettl D, Kropsch M, Mandl M (2018) Odour assessment in the vicinity of a pig-fatting farm using field inspections (EN 16841–1) and dispersion modelling. Atmos Environ 181:54–60

Oettl D, Kropsch M, Zentner E, Bachler G, Pollet A (2018c) Geruchsemissionen aus der Tierhaltung, Amt der Stmk. Landesregierung. Report Nr. LU-06–18, 16 pp http://app.luis.steiermark.at/berichte/Download/Fachberichte/Lu_06_2018_Emissionsfaktoren_C.pdf

Ogink NWM, Lens PN (2001) Odour emissions from livestock operations (original title: Geuremissie uit de veehouderij.

Overzichtsrapportage van geurmetingen in de vakrensehoudrij, pluimveehouderij en rundveehouderij). Institute for agricultural and Environmental Engineering IMAG-DLO, Netherlands
Schauberger G, Piringer M, Eder J, Fiebiger H, Köck M, Lazar R, Pichler-Semmelrock F, Quendler Th, Swoboda M, Thiemann G, Teufelhart J (1997) Austrian guideline to assess ambient air pollution from livestock buildings. Gefahrstoffe Reinhalt Luft 57:399–408
Stoll S (2019) Erstellung von Polaritätenprofilen für das Konzept Gestand und Duft für die Tierarten Ziegen und Schafe, VDI Berichte 2362. Gerüche in der Umwelt, Germany, pp 171–174
Sucker K, Both R, Bischoff M, Guski R, Krämer U, Winneke G (2008) Odor frequency and odor annoyance part II: dose-response associations and their modification by hedonic tone. Int Arch Occup Environ Health 81:683–694
Sucker K, Hangartner M (2012) Die Methode der Polaritätenprofile zur Beurteilung der hedonischen Geruchsqualität - Reliabilität und Validität, 72, 411–417
Sucker K, Bischoff M, Krämer U, Kühner D, Winneke G (2003) Untersuchungen zur Auswirkung von Intensität und hedonischer Geruchsqualität auf die Ausprägung der Geruchsbelästigung. Forschungsbericht des MIU, Düsseldorf und der Fa. deBAKOM, Odenthal im Auftrag des MUNLV NRW (Hrsg.), Düsseldorf, 126 pp
VDI 3788–1 (2000) Environmental meteorology – dispersion of odorants in the atmosphere - fundamentals German Engineering Association VDI Düsseldorf 25
VDI 3894–1 (2009) Emissionen und Immissionen aus Tierhaltungsanlagen Haltungsverfahren und Emissionen Schweine, Rinder, Geflügel, Pferde Düsseldorf 46
VDI 3940–1 (2006) Measurement of odour impact by field inspection - measurement of the impact frequency of recognizable odours - Grid measurement. Düsseldorf
VDI 3940–4 (2010) Determination of the hedonic odour tone - polarity profiles. Düsseldorf
Weitensfelder L, Moshammer H, Oettl D, Payer I (2019) Predicting odor complaints. Environ Sci Pollut Res Int 26(10):9806–9815
Winkler G (2017) Ableitung von tierspezifischen Gewichtungsfaktoren für Pferde und Mastbullen. Erstellung von Polaritätenprofilen für das Konzept Gestank und Duft für die Tierarten Mastbullen, Pferde und Milchvieh. VDI Berichte 2315, Gerüche in der Umwelt, Germany, 23 – 30