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Temporal Trend of Odour Emission of Livestock Buildings for Fattening Pigs Due to Climate Change

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Odour is one of the most relevant pollutants of livestock buildings. To limit the odour annoyance, separation distances are calculated to guarantee a far-reaching protection level for residents living in the vicinity. Usually, the odour emission rate is determined as an annual mean value. Due to the impact of the indoor temperature and the ventilation rate on the odour emission of livestock buildings, the possible impact of the climate change signal on the emission was analysed to find out if this effect has to be considered when calculating the separation distance. This has to be taken into consideration to avoid a possible underestimation of the separation distances by this temperature effect which are used for the zoning and licencing of livestock buildings. The impact of the climate change signal was investigated by a simulation of the indoor climate of a confined livestock building with a mechanical ventilation for 1800 fattening pigs determined yearly for the period 1981 to 2017 and the odour emission modified by these parameters. The odour emission increased by about 0.16% per year. The relative increase of the separation distances for the four cardinal directions is about 0.06% per year, the related increase for the separation area is 0.13% per year. This means that the climate change will not show a relevant impact on the separation distance.

1. Introduction

Airborne emissions of livestock buildings are a relevant impact on the environment with odour and ammonia (NH_3) as the most important pollutants (Blanes-Vidal et al., 2012a). Whereas odorous substances are more relevant on a local scale causing annoyance of the residents, ammonia is a pollutant, which is predominantly relevant on a regional scale. Odour is one of the major annoyances from livestock husbandry especially in the pig industry (Cantuaria et al., 2017). Odour emissions have been known to reduce the quality of life of residences (Blanes-Vidal et al., 2012a; Blanes-Vidal et al., 2012b; Cantuaria et al., 2017; Wing et al., 2008) and the self-reported health status (Wing et al., 2014). This can result in a negative impact of the economic development around these facilities (Gómez and Zhang, 2000; Herriges et al., 2005).
In this study we investigated the impact of climate change on the emission of odorous substances and the resulting separation distances.

2. Materials and Methods

2.1 Meteorological data

For the calculation of the indoor climate and the related emission of odorous substances, meteorological data are needed on an hourly basis (air temperature and relative humidity). The Austrian Meteorological Service

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ZAMG (Zentralanstalt für Meteorologie und Geodynamik) provided measurements for the weather station close to the city of Wels (48.16°N, 14.07°E) for the time period 1981 to 2017. For the whole area of Upper Austria, a mean increase of temperature is expected with values of ~+1.4°C (~± 0.5°) until the middle of the century.

2.2 Simulation of the indoor climate

The indoor climate is simulated by a steady state model which calculates the thermal indoor parameters (air temperature, humidity) and the ventilation flow rate. The thermal environment inside the building depends on the kind of livestock, the thermal properties of the building, and the ventilation system and its control unit. The core of the model can be reduced to the sensible heat balance of a livestock building (Schauberger et al., 2014b; Schauberger et al., 2000, 2001). The model calculations are performed for a typical livestock building in Central Europe for fattening pigs of 1800 heads, divided into 9 sections with 200 animals each, using meteorological data on an hourly basis for the time period between 1981 and 2017.

The livestock emissions are calculated separately for each section assuming an all-in-all-out production cycle. The body mass values at the beginning and the end of the fattening period were selected to be m_{start} = 30 kg for t = 0 d and m_{end} = 120 kg for t_A = 108 d with the corresponding time of the Gompertz model (Mikovits et al., 2017). The duration between two consecutive fattening periods, when the livestock building is serviced (cleaning and disinfection), is assumed as t_S = 10 d. Hence the overall duration of a fattening period is given by $t_{FP} = t_A + t_S$ which results in t_{FP} = 108 d + 10 d with a duration of t_{FP} = 118 d. Therefore the number of fattening periods per year is given by n_{FP} = 365 / t_{FP} with n_{FP} = 3.09.

2.3 Airborne emissions

In general, the odour emission rate of a livestock building is calculated by a specific emission factor e_0 which is related to the body mass (livestock unit LU, 1 LU = 500 kg). This reference emission rate is an annual mean value $e_{0,OD}$ = 50 ou $s^{-1}LU^{-1}$ (VDI 3894 Part 1, 2011).

The odour release is modified by the indoor climate (e.g. temperature, ventilation rate and time of the day) of the livestock building (Schauberger et al., 2013; Schauberger et al., 2014a). The modification by these predictors is considered by the release modification factor R according to $e = e_0 R$.

The release modification factor R is calculated on the basis of the indoor air temperature T_i, the ventilation rate V, and the physical activity of animals A as a function of daytime t (Schauberger et al., 2013; Schauberger et al., 2014a; Schauberger et al., 2014b) by $R = F_T F_V F_A$ with the three corresponding functions F_T for indoor temperature, F_V for ventilation rate and F_A for relative animal activity.

The exponential function for the indoor temperature F_T describes the increase of the odour release with the indoor temperature T_i (°C) given by $F_T = e^{c_T(T_i - T_R)}$ where c_T = 0.0314 is the coefficient for the exponential function, and the reference temperature T_R = 20°C. The function for the ventilation rate F_V is parameterized by the normalized ventilation rate V_n per animal place using the following power function $F_v = V_n^{c_v}$ where the exponent is c_v = 0.318. The ventilation rate per animal place V is normalized to unity by V_d, according to $V_n = V/V_d$ using V_d = 200 $m^3 h^{-1}$ per animal place. The diurnal variation of animal activity F_A is described by a function which is used for the diurnal variation of the energy release as well (Mikovits et al., 2017),

$$F_A = A_0 + a \sum_{i=0}^{k} \frac{\sin\left(\frac{2\pi}{\tau}(2i+1)(t+\varphi)\right)}{2i+1} \tag{1}$$

with the amplitude *a*, the period τ = 24 h, time of day t (h), time lag φ(h), and k = 1. The reference value for the daily mean of the relative animal activity is A_0 = 1.

The release modification factor $R = F_T F_V F_A$ is thus given by

$$R = \exp\left(0.0314\,(T_i - T_R)\right) V_n^{0.318} \left(1 + 0.25 \sin\left(\frac{2\pi}{24h}(t-6h)\right) + \frac{0.25}{3} \sin\left(\frac{2\pi}{24h} 3(t-6h)\right)\right) \tag{2}$$

The release modification factor is normalized to unity by the annual mean value of R_{1981} for the year 1981, using a linear regression for the annual mean values R_i between 1980 and 2017. This relative release modification factor $r = R / R_{1981}$. The emission factor is calculated by $e_{OD} = e_{OD,0}\, r$. The odour emission rate of the entire livestock building is calculated by $E_{OD} = N\, m_M\, e_{OD}$ (ou s^{-1}) with the number of animals N = 1800, the mean body mass m_M = 75 kg (m_M = 0.15 LU) and the body mass specific odour emission factor e_{OD}.

2.4 Separation distance and separation area

For the odour emission, the related direction depending separation distances can be calculated on an annual basis. These distances can be used to determine the area which is essential to operate such a livestock building. The separation distances are calculated by an empirical model which was developed for Austria (Schauberger et al., 2012a). The necessary input parameters are the annual mean value of the odour emission rate E_{OD}, the wind statistics for the site for 10° sectors (mean wind velocity and frequency of the direction for 1993), and the odour impact criterion, which is given by the odour exceedance probability P (%), describing the odour protection level for residents, and an odour concentration, usually the odour threshold of 1 ou_E m^{-3}. The equation for the separation distance D_{Sep} (m) reads as

$$D_{Sep} = P^{-0.386} (165\,F^{0.0289} - 3.63\,W - 150)\,E^{\frac{1}{-0.0381\,F + 0.0191\,P + 2.31}} \quad (3)$$

depending on the relative frequency F (%) and the mean wind velocity W (m/s) for each 10° sector of the wind direction, as well as the exceedance probability for odour perception P = 15%, which is a typical value for agricultural areas (GOAA, 2008).

The separation distance $D_{Sep,i}$ is calculated for all 36 wind directions i (10° sectors). The separation area A_{Sep} which is needed to conduct animal husbandry without complaints by the neighbours is calculated by

$$A_{Sep} = \frac{\pi}{36} \sum_{36}^{i=1} D_{Sep,i}^2 \quad (4)$$

To emphasize the impact of the meteorological situation on the direction depending separation distance D_{Sep} and the separation area A_{Sep}, the calculations are performed with a wind statistics which doesn't change in time. The temporal variability of the separation distance D_{Sep} is shown for the two prevailing wind directions (East and West) and the two additional wind directions North and South which are influenced by a thermal driven wind regime (valley winds) at this site (Schauberger et al., 2006).

2.5 Model calculations and sensitivity analysis

The model calculations are performed for the entire growing-fattening period for a body mass between 30 and 120 kg. The calculations are done for 1981 to 2017 to determine the trend for the 37 years period. Additionally, we selected the years 1984 and 2015, as one of the coldest and warmest years for summertime measured in the last decades, to show specific results outside of the trend calculations.

The trend is estimated with a linear function $x_{trend} = b\ x + a$ for the period 1981 to 2017. The inter-annual variability is calculated for the detrended values x' with $x' = x\ \ x_{trend}$.

3. Results and Discussion

The two parameters, indoor air temperature T_i and volume flow rate V, which modify the release of odorous substances, show a negligible trend for the annual mean values (Table 1). For the odour emission rate a relative trend of 0.16% per year could be determined. The annual mean value of the relative release modification factor r lies in the range of 98% for 1984 as a cold year and 108% for the hottest year in 2015, shown in Figure 1. The relative increase of the separation distances for the four cardinal directions is about 0.06% per year, the related increase for the separation area is 0.13% per year.

Table 1: Statistics of the predictors and the related odour and ammonia emission by the use of the mean annual linear trend, the mean relative trend (% per year) the reference value for 1981, minimum (Min), and maximum (Max) between 1981 and 2017 for the indoor air temperature T_i (°C), the cumulated volume flow rate per animal place V_a (10^3 m³ a^{-1}), the animal mass related odour emission factor e_{OD} (ou s^{-1} LU^{-1}), the release modification factor r, the separation distances D_{Sep} (m) for the four cardinal directions, and the separation area A_{Sep} (ha).

	Trend (per year)	**Rel. Trend** (% a^{-1})	**Reference 1981**
Predictors			
Indoor air temperature T_i (°C)	0.023 ± 0.004	0.12 ± 0.023	18.7
Volume flow rate V_a (10^3 m³ a^{-1})	0.881 ± 0.157	0.26 ± 0.046	340
Odour Emission			
Odour emission factor e_{OD} (kg s^{-1} LU^{-1})	0.079 ± 0.001	0.16 ± 0.03	50
Relative release modification factor r (-)	0.002 ± 0.000	0.16 ± 0.03	1.0
Separation distance D_{Sep} (m)			
North	0.079 ± 0.015	0.06 ± 0.01	136
East	0.176 ± 0.033	0.07 ± 0.01	270
South	0.045 ± 0.008	0.06 ± 0.01	79
West	0.202 ± 0.038	0.06 ± 0.04	313
Separation area A_{Sep} (ha)	0.0133 ± 0.0025	0.13 ± 0.024	10.19

The annoyance due to the emission of odorous substances is handled in most of the jurisdictions by the use of a direction depending separation distance. This distance between odour sources and residential areas is used to divide the circumjacent area around a source in a zone which is widely protected from annoyance and a zone closer than the separation distance where nuisance can be expected to a certain extent. The protection level (Brancher et al., 2016; Sommer-Quabach et al., 2014) depends also on the land use category. The higher the protection level, the farther the separation distance. The calculation of the separation distance can be performed by the use of an annual mean value for the odour emission flow rate and a dispersion model (Piringer and Schauberger, 2013) or by a simplified empirical model (Schauberger et al., 2012a; Schauberger et al., 2012b). To analyse the impact of climate change we used the empirical model for Austria (Schauberger et al., 2012a) and the wind statistics of Wels with the frequency of the wind direction for 10° classes and the corresponding mean wind velocities for 1993. By this approach the inter-annual variability due to the change of the odour emission flow rate was determined. The results show nearly constant separation distances for the cardinal wind directions. Also the separation area doesn't show a significant increase due to the climate change signal.

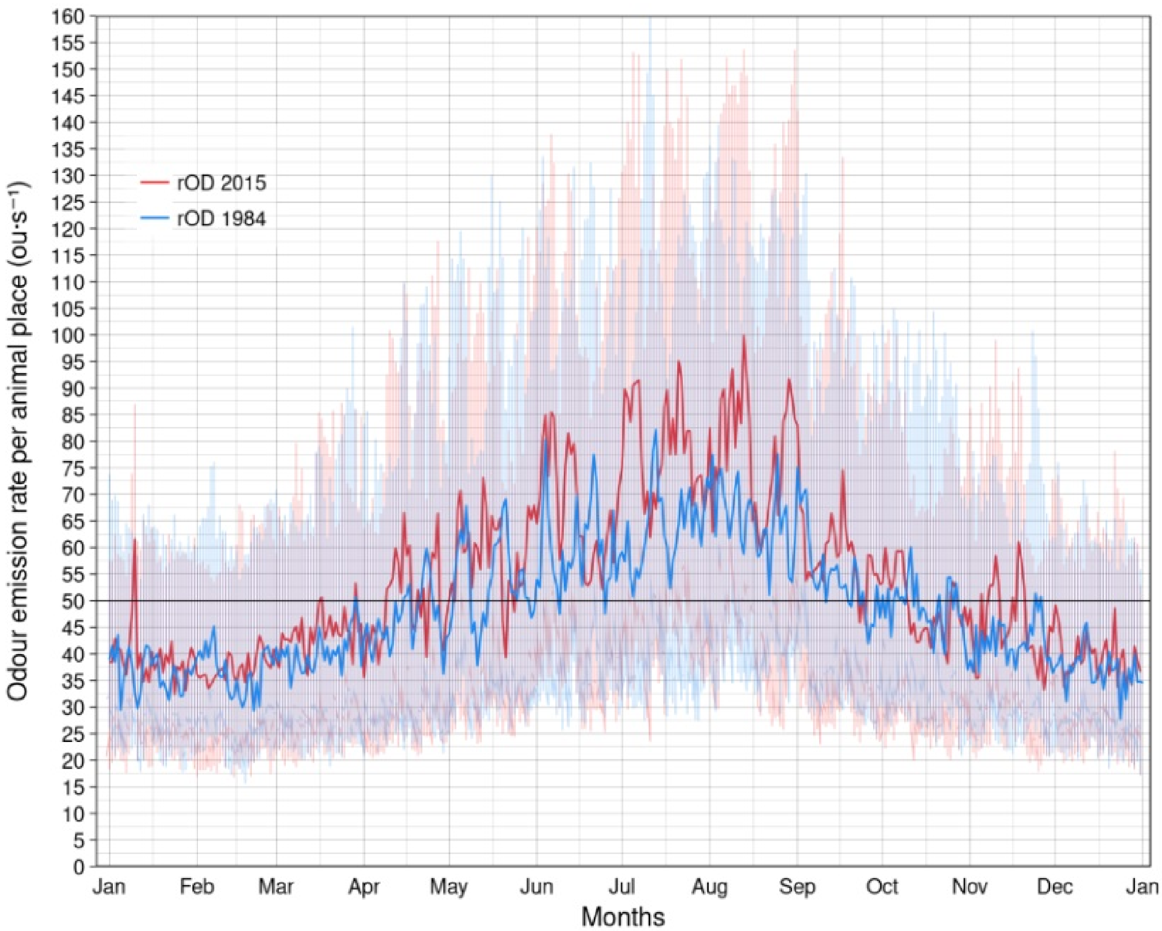

Figure 1: Time course of the hourly values of the body mass related odour emission factor e_{OD} (kg s^{-1} LU^{-1}) for 1984 (cold, in blue) and 2015 (warm, in red). The reference value of the odour emission factors is $e_{0,OD}$ = 50 ou $s^{-1}LU^{-1}$, shown by a thin black line. The blue and red lines represent diurnal mean values.

This means, that the calculation of the separation distances is not sensitive to the climate change impact. The meteorological dilution conditions, which are related to the wind direction, wind velocity, and stability of the atmosphere show a much stronger inter-annual variability (Brancher et al., 2018a; Brancher et al., 2018b). This promising result shows that the impact of the climate change signal on the annual emission rate is quite low and that the determined separation distances will be valid even on a long term perspective. Due to the fact that these calculations are performed for zoning and licensing of livestock buildings, this is an important feature for a high predictability and reliability of legal decisions.

Due to the fact that the odour emission has an economic impact as well by the consumption of land to guarantee the separation distances and the loss in value due to odour annoyance (Bazen and Fleming, 2004; Hribar and Schultz, 2010), climate change has no additional impact.

4. Conclusions

The impact of climate change is a relevant issue in the field of air borne emissions. For the odour emission of livestock buildings the indoor climate was simulated over more than three decades to investigate the impact on the annual mean emission factor. Beside the meteorology, the emission factor is the relevant parameter to calculate the separation distance to avoid odour annoyance. The economic consequence was investigated by the separation area which is circumvented by the direction depending separation distances. The relative trend of the odour emission lies in the range of about + 0.16% per year which gives an increase of about 3% between 1981 and 2017. The relative increase of the separation distances for the four cardinal directions is about 0.06% per year, the related increase for the separation area is 0.13% per year. For this case study for fattening pigs it could be shown that the climate change signal has a negligible impact on the odour emission and the related separation distances. Therefore current and near future zoning and licensing of livestock building are based on reliable emission data.

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