



Abatement control and regulation of emission and ambient concentration of odour and allergens from livestock farming

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Preface

Livestock farming is facing general environmental concern in the public, due to a general increase in the concentrated animal feeding operations (CAFO). The trend in swine, poultry, and cattle operations is toward fewer but increasingly larger operations. Predictions in Finland are pointing at an average size of livestock farming units during the period from 2001 to 2010. In Denmark, the number of CAFO's is expected to follow a similar trend. In Sweden, the number of CAFO's is expected to increase, but not in the same scale.

Another trend is the increasing use of horses for sport and recreation. Many horses are situated in close vicinity of residential areas and with activity in the urban periphery.

The ambient air inside the animal housing facilities contains a variety of gases, odours, dust particles and micro-organisms that are discharged to the surrounding environment by the ventilation systems. The complexity of emissions of airborne particulates from animal production and the associated health problems involve numerous stakeholders. This publication provides a brief overview of the current Nordic situation and is intended to initiate a discussion on how to target the problem.

A significant outcome of this project has been the creation of a network of Nordic researchers that has participated in identifying the respective national situations related to abatement, control and regulation of allergens and odours emitted from livestock production. A Nordic Workshop was held in March 2007 at the Carlsberg Academy in Copenhagen. The aim of the workshop was to discuss national research focus and develop a project frame for a Nordic review of current research and policy issues related to odour and allergen dispersion from livestock farming.

The member institutions of the Nordic network are: from Denmark; the National Environmental Research Institute (NERI), Research Centre Bygholm, Institute of Public Health all three are part of Aarhus University. From Finland; Technical Research Centre (VTT), The Finish Meteorology Institute (FIM), the Finish National Public Health Institute, Department of Environmental Health. From Sweden; participated Jordbruksverket, Dept. of Agricultural Biosystems and Technology, Boverket, and The Swedish University of Agricultural Sciences. Norway is represented by The Norwegian Meteorological Institute.

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Summary

The public's concern about the potential health effects of airborne emissions from livestock farms has increased in recent years due to the increasing size of livestock production units. The concentration of animal production in larger units has been driven by many factors among these is the market oriented competition for meat, poultry, milk, and eggs. Urban centres have in many places moved into what used to be rural farming areas. Emissions of odour and allergens related to animal production are of significant concern not only to new residents in these areas, but also to those who have been living in close vicinity of livestock production facilities for many years.

Environmental impacts of the agriculture are partly caused by airborne pollutants. Ammonia, methane, nitrous oxide and odour are pollutants released to surrounding environment with well known effects such as eutrophication, acidification, climate change and annoying perception.

Volatile organic compounds (VOC's) and the previously mentioned number of other gases as well as particulate matter are emitted from the animal production facilities. Apart from PM10 and PM2.5, biological aerosols are regarded as a potential health risk. The VOC's-PM interactions are known as an important pathway for carrying odour.

The particles emitted from livestock farms may carry substances such as endotoxins and antibiotic residues, and these particles remain suspended in the air for some time due to their limited dimensions and can therefore be inhaled by animal and man. Strong epidemiological evidence suggests that bacteria in dust particles may cause infectious and allergic diseases in animals as well as in farm workers. These compounds are emitted in large amounts and released to the surrounding environment and thereby they contribute to the local pollution load.

Exposure in swine confinement buildings is known to be the cause of breathing impairment and loss of lung function in farmers, and it may therefore also be a risk factor for nearby residents.

A survey on current practise and an ongoing policy regarding abatement, control and regulation of emissions and ambient concentrations of odour and allergens from livestock farming in the Nordic countries are intended to form the basis of a common Nordic strategy in this area. Such a strategy is considered as an important element in protecting the population in the Nordic Countries from exposure beyond certain thresholds to odour and/or allergens as well as other livestock related annoyances and health hazardous compounds. This project is foreseen to strengthen the knowledge exchange and cooperation between the Nordic countries and will expectantly lead to address the urgent matter more widely in EU. The

goal of this project is to investigate to what extent the various Nordic countries have developed national strategies in order to control and regulate odour annoyance and allergens released from livestock farming.

Achievement

Emission rates from allergens and odour compounds from livestock facilities are influenced by a range of local factors including type of facility, practise in manure management, the building design and the applied ventilation rate. Certain lacks of unanimity in published emission data address the need for an improved national data management strategy.

Danish experimental studies indicate that the odour emission from pig production can be reduced by cooling of the inlet air. Management factors in order to control the thermal comfort of the pigs are essential, as the ventilation rate must not be too high in relation to the odour emission, or too low in relation to the dunging behaviour.

The tasks

The main objective of this work was to find out whether the agricultural setting in the Nordic countries is posing an annoyance or health risk to neighbouring residential areas. The work is based on a literature review and interviews and discussions with national experts and has lead to a survey on the following topics regarding allergens and odour from livestock production:

- Overview of the Nordic livestock production
- Review of reported health implication related to livestock farming
- Status for current knowledge on perception and definition of odour annoyance
- Review of bioaerosol sampling and collection
- Collecting information regarding practice of national environmental odour enforcement
- State-of-the-art in the Nordic countries concerning modelling dispersion of odour
- Outline of potential strategies for abatement and control of odour and allergens
- Review of Nordic Policy on regulation and control of livestock farming

Recommendations

It is recommended to enforce better risk communication between farmers, authorities and the population living in the close vicinity of livestock facilities. Better communication may improve the awareness of the farmers and reduce the perceived annoyance.

A chimney on the animal house may increase the dilution of the emitting substances and high subjects, such as trees, around the house may in some cases help to achieve more local turbulence and thereby improve dispersion of the emitted compounds. At the same time it may reduce the perceived annoyances in the cases where the actual emission is low.

Treatment of ventilation air is another pathway to reduce emissions from the animal buildings. In this regard, biofilters are a costly but also efficient pollution abatement strategy, and may reduce odour emission with up to 75%.

Much effort has been made to reduce the annoyance in nearby surroundings, although further research on the relationship between ammonia and odour is necessary in order to determine the importance of potential agents in odour formation as well as for investigating the potential for using ammonia measurements as indicator of odour levels.

The general recommendation for reducing odour and allergens from livestock farming is:

- Airflow and temperature in manure storage must be minimised
- The livestock manure must be stored in sealed containers with a permanent top cover
- When applying the manure on the field, it must be placed close to vegetation cover or injected directly into the soil.

Research on adverse health effects should be divided into susceptible subgroups. In comparison with the rest of the population, especially asthmatic children and elderly have been identified as more sensitive to respiratory health effects related to microbial exposure from farm houses.

A major part of the on-going projects on air emissions from agricultural sources relates to monitoring and abatement of greenhouse gases. There is, however, a need to revise the current general guidelines for livestock production and the current emphasize on the actual odour impact. Little data is available e.g. on odour emissions from cow sheds and from fur production.

1. Background and introduction

There is a growing concern in the population in the Nordic countries regarding the health impact in connection with the releases of odour and allergens and other compounds from farm houses and Concentrated Animal Feeding Operations (CAFO) with a potential health impact (Nimmermark, S. 2004; Herlin, A. 2006; Schulze, A. *et al.* 2006). Complaints from neighbours to livestock farm houses about odour are getting more and more common (Dalton, P. 2002). All types of animal households may potentially lead to odour problems, although pig production appears to be the most important source of annoyance problems in this regard (Nimmermark, S. 2001). Airborne allergens emitted from horses have been the subject in a debate that has taken place in Sweden, due to an increased population of horses near residential and peri-urban areas (Herlin, A. 2006). In Sweden, 75% of all houses are found in urban or peri-urban areas, a similar trend is seen both in Southern Finland and north-eastern Denmark (Neumann, K., *et al.* 2008).

Ammonia has been in focus in Europe and in the US for a number of years. In Europe, concern about NH_3 has mainly been in relation to eutrophication problems, whereas in the US NH_3 is mainly regulated in order to control aerosols formation as $\text{PM}_{10}/\text{PM}_{2.5}$ from livestock is considered as a health problem of concern (Wing, S. and Wolf, S., 2000)

Odour and gases related to agricultural activity are an international problem partly due to the intensification of concentrated animal production and partly due to the increasing urban population moving closer to farming and livestock production units (Kai, P. 2006). In Denmark an increasing pig production has increased the odour problems during the last decade (Takai, H. 1998). In Sweden, the horse holds and horse activities close to urban settings have not been larger than today thought-out history, and horses in Sweden have recently been targeted as a major bioaerosol source (Herlin, A. 2006). Thousands of different odour and bioaerosol compounds released from livestock farming have been identified. The human nose is able to distinguish about 10,000 different odour compounds. Odour from livestock farming is usually a mixture of many compounds. The combination of some of these may enhance the odour whereas others may eliminate each other (Thorne, P. 1998). A number of compounds that may be difficult to detect separately may in some cases lead to a strong smell. More than 200 odour compounds have been identified in manure. Although odour is in gas phase, some compounds in the release may be associated with dust particles but are later volatilised (Nimmermark 2004).

The total particle emissions (TSP) from agricultural sources are estimated to 5,530 Gg per year in Europe (FAO 2007). In Finland is this equal to 7% of the national total TSP's emission. Dust emitted from housing units contributes to odour transport and plumes may have potential for transmitting diseases to other housing units or neighbours. Odour is combined with higher concentrations of endotoxins in the surroundings of a farm. This is currently investigated with regard to potential effects on health of farmer families and neighbouring residential (Schulze, A. *et al.* 2006). At the same time, a Finnish study has indicated that newborns' exposure to microbes related to livestock farming diminishes the child's risk of developing allergies (Roponen *et al* 2005).

The Hygiene Hypothesis

The hygiene hypothesis proposed by David P. Strachan postulates that growing up in a more hygienic environment may increase the risk of developing allergies (Liu and Leung, 2006). This hypothesis has been prompted by the results of epidemiological studies showing that overcrowding and unhygienic conditions were associated with a lower prevalence of allergies, eczema and hay fever as well as asthma. Infection and exposure to certain microbial agents early in life have been proposed as an explanation of these protective effects (Douwes *et al.*, 2005, Liu and Leung, 2006). In particular, several cross-sectional studies have reported significant inverse association between indoor endotoxin levels and atopic sensitization, hay fever and atopic asthma. A recent prospective birth cohort study showed an inverse association between floor levels of bacterial endotoxins and fungal components measured during three months and doctor diagnosed asthma and persistent wheeze at the age of 4, confirming some of the earlier findings from cross sectional studies (Douwes *et al.*, 2004, Liu and Leung, 2006). Several studies have also reported a reduced risk of atopy, hay fever, asthma and eczema in farmers children and adolescents, and although the specific protective factors were not conclusively determined, an important role of endotoxin and other microbial agents has been suggested (douwes *et al.*, 2006). However, there are several large studies that have not shown a protective effect, or even found a positive association.

However, the hygiene hypothesis alone does not provide an adequate explanation for the observed increase in allergic disease. It has been suggested that lifestyle changes are associated with asthma (Radon, K. *et al.* 2004). Other suggestions target the progressive decrease in physical activity, and others again the housing conditions (Mirabelli, M. C., 2006; Eder, W. *et al.* 2006). It is a fact that airborne exposure such as allergens and odour from livestock farming is causing health implication. It is also a fact that the incidence of asthma has increased among children and adolescents. Individual susceptibility, for example, atopy, allergic sensi-

sation, or immunodeficiency poses an important role in the risk assessment of bioaerosol pollution (Radon, K. *et al.* 2006; Eduard, W., *et al.* 2004). It is essential that we keep thinking broadly about the factors responsible for the rising incidence of health implication related to the changing livestock production.

Bioaerosols and livestock production

The sources of bioaerosols are largely the animals themselves: their feed, stools, faeces and dried urine with some allergens from skin and hair (Verein Deutscher Ingenieure, 1997). Additional components originate from insects and microorganisms thriving on the organic material in animal buildings (Radon, K. *et al.* 2004.; Eduard, W., *et al.* 2006)

Disinfectants and other applied agents are also present, and may in some cases add to the adverse health effects of workers (Preller *et al.*, 1995b). Airborne particles usually act as a vector for pathogenic bacteria, viruses, endotoxins, odours material, gases and liquid substances (Verein Deutscher Ingenieure, 1997). Viable bacteria and vira carried by the dust particles may have greater ability to survive and thereby constitute a local health risk (Wang, Z. *et al.* 1997; Wing, S. and S. Wolf, 2000).

Bacteria thrive in the environment of the farm houses and cause high air concentrations of bacteria, endotoxins, and other bacterial components. The fungal load in animal houses with concrete floors without litter is likely to originate primarily from outside air. For livestock raised on litter or animals fed on hay, fungi probably originates to a great extent from the indoor environment (Thorne, P., 1992). This is important, since fungal spores appear to be closer associated with the asthma prevalence in livestock farmers than endotoxins (Eduard *et al.*, 2004a). Bioaerosols containing this type of components have repeatedly been found to induce lung function changes, upper airway and mucosal inflammation, symptoms and systemic inflammatory reactions in adults exposed to them (Thorne, P.1992; Radon, K., 2004).

Concentrations of airborne bacteria may be very high in the vicinity of livestock farms (Duchaine *et al.*, 2000, Donham *et al.*, 1986, Attwood *et al.*, 1987b). Gram-positive bacteria dominate this population as they easily represent 90–95% of the total amount of bacteria. Experimentally, endotoxins are capable of inducing many of the symptoms associated with livestock exposure, including fever reactions as seen in organic dust toxic syndrome and farmer's lung and worsening of asthma with cough and breathlessness. Thus, it is not surprising, that endotoxins have drawn much attraction. Several epidemiologic investigations have found that respirable endotoxins in the farming environments were closer associated with adverse effects on the airways and immune system than were airborne dust levels (Thorne, P., 1992; Radon, K., *et al.* 2004c; Takai, H. *et al.* 2006).

2. Method and network

Method

The main aim of this report is to present a survey of the existing literature, models, available data regarding odour and allergens released from livestock farming and Nordic policy guidelines on odour annoyance thresholds. The report begins with a description of the agricultural practice in Scandinavia followed by a survey of reported associated health effects mainly focused on exposure to allergens. The following section described the complexity of odour management and odour perception. Chapter 6 includes a brief overview of implied dispersion models in the Nordic Countries and ends by addressing national odour thresholds as well as potential policy implications and by suggesting target points for a possible future Nordic strategy in this area.

Nordic meeting

An important part of the network building of this current project took place in connection with the Nordic workshop in Copenhagen in March 2007. The workshop was organised in order to describe national strategies and research focus on odour management and dispersion of allergens from livestock and in order to initiate the creation of a Nordic network where this topic could be discussed.

Network

The network formed at the Nordic workshop, included mainly Swedish, Finnish and Danish participants as the most active partners together with contributions from Holland, Polen and Germany. No Norwegian participant was initially involved but the network is still open for new participants to join.

Interdisciplinary

The study of odour annoyance and dispersion of allergens is a highly interdisciplinary endeavour soliciting the interest of medical doctors, epidemiologist, ecotoxicologist, biologist, biochemist, geophysics, engineers as well as, decision,- and policymakers. The goal of the network is to bring together researchers from different fields in order to facilitate an ongoing exchange of knowledge across disciplinary barriers. The project will foster interdisciplinary collaborations in the Scandinavian region.

Thereby the authors of this report wish to improve the overall understanding of the health and environmental impact of odour and allergens emitted from livestock farms.

The aim

The aim of this project is to form a review of odour and allergen implications on human health and to collect and compare current policy in the Nordic countries, in relation to abatement, control and regulation of odour and allergens from livestock production. An important part of this task is forming a Nordic network including key experts in the relevant fields of environmental and health research and using this network as a forum to discuss gaps in current and coming national policies. The report identifies knowledge gaps which will be redirected into specific needs for knowledge acquisition and further research, aiming at improved methodologies, technologies and encourage interaction of stakeholders and so fourth. In this way, the work will outline future topics of concern and how to target this important matter in future. The report will provide a Nordic close-up of the field of allergens and odour annoyance from livestock. The interdisciplinary of the network has allowed all participants to address individual scientific focal points and contribute views on the subject provided by themselves and other colleagues in other fields. Thus the establishment of a cross-European collaboration and a platform for discussion will be formed, allowing the European research community to join forces in the existing field of research.

Literature and information

Scientific articles, governmental recommendations, national policy strategies as well as other relevant literature have been analysed. The non-scientific literature is mainly popular reports and newspaper articles reflecting the tendencies in the studied areas. Actions by governments, parliaments and authorities have also been gathered. The review has a key focus on management and previous research experience in a Nordic context.

3. Livestock agriculture

Recent years have shown an intensification of large scale animal production units, especially in connection with the pig and poultry production. Farmers are faced with growing criticism and scepticism from neighbouring communities and they are likely to meet an increasing concern for further enlargement and industrialisation of the agricultural sector (van Strien, R. T. 2004). The public's concern include annoyance from odour, acidification, animal welfare and risk from airborne diseases. Besides the regulation and future targets on volatile emissions and other airborne agents are essential in order to elaborate the development of the agricultural sector.

3.1 Livestock husbandry systems in Europe

The relations between man and animals have changed over the past decades (Neumann, K., *et al.* 2008). As an example, horses are now mainly used for leisure purposes (Herlin A. 2006), and the industrialisation of the agricultural sector is leading towards larger livestock production units. The intensive animal production system in the Nordic countries comprises some 17 million pigs and nearly 11 million laying hens and more than 4 million cattle in stables, confined within an area of about 786,670 ha. The agricultural sector in Denmark is covering more than 75% of the Nordic meat share (EURO stat November 2007).

In comparison with other intensified livestock production countries, the Netherlands alone comprise some 14 million pigs and nearly two million cattle, as well as 100 million chickens, 33,000 square kilometres.

The livestock sector is growing at an unprecedented rate, due to an increased demand for livestock products, the intensification of livestock production is taking place internationally, and will in particular lead to an increased concern in relation to potential annoyances and health risks in the most affected areas. This may lead to implementation of a new and cleaner technology in order to improve indoor air quality, odour, and noise annoyance and in order to place concentrated animal feeding operations in areas where it does not annoy the local communities. A few but larger production units are usually easier to administrate for the environmental decisions makers and will normally adopt environmental legalisation more efficiently.

The pattern in food consumption is becoming increasingly similar throughout the world, incorporating more meat and dairy products. This trend is associated with increased international trade in foods. This shift

towards intensive animal production favours the largest livestock farmers or enterprises, and progressively incorporate farming into a wider agro-industrial complex can lead to environmental degradation and negative impact of life quality of those affected.

3.2 Livestock production in the Nordic countries

The livestock production in the Nordic countries has followed a similar trend as the rest of Europe. The agricultural sector, especially in Denmark, has developed within 30 years from small multi livestock holds to large concentrated animal feeding operations with primarily one livestock class. In figure 3.1, the last ten years illustrate the decline in numbers of farms.

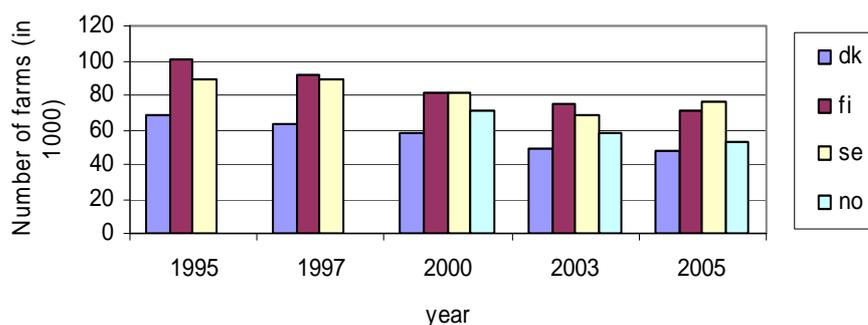


Figure 3-1 Number of farms in the Nordic countries from 1995 to 2005 (Euro STAT Nov 2007)

During the last decade most livestock units in the Nordic countries have been industrialized, resulting in an increased number of large operations raising thousands of animals in single facilities. Industrialized livestock production units achieve economic growth by focusing on solitary homogeneity livestock, e.g. same age, same food, same growth. These changes in animal production systems, combined with changing community demographic, have considerably narrowed the interaction between farming-urban interface and have resulted in a growing public concern over the potential occupational, environmental and community risk posed by their large concentrated animal feeding operations (CAFO's) (Cole et al., 2000).

Pig farming in the Nordic countries

Pig farming in the Nordic countries is dominated by commercial pig breeds. Denmark holds more than 75 % of all pigs produced in the Nordic countries (Euro STAT November 2007). Figure 3-2 shows the number of

pigs in the Nordic countries. The number of pigs held in Denmark has increased from less than 10 million in 1990 to more than 12.5 million in 2006. The other Nordic countries have fixed numbers except from Sweden that has experienced a decline in the annual number from above 2,25 million in 1998 to less than 1.7 million in 2006 (around 40%). [FAO 2007].

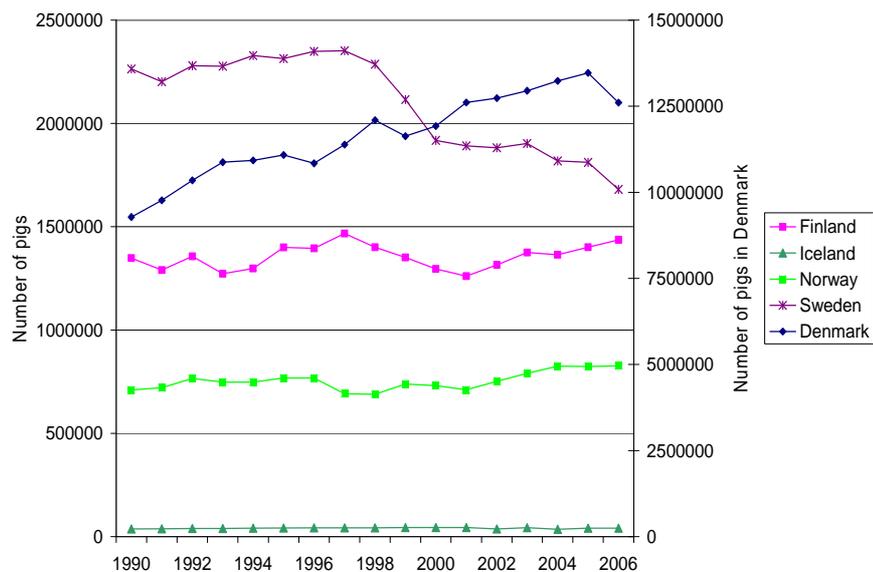


Figure 3-2 Number of pigs in the Nordic countries from 1990 to 2006, left Y-axis shows the number of pigs held in Finland, Iceland Sweden and Norway. Right Y-axis shows the number of pig held in Denmark. [FAO 2007]

Horses hold in the Nordic countries

The numbers of horses have increased considerably since the 1990's in all Nordic countries. After the second industrialization of the agricultural sector between the 1970's to the 1980's the use of the horses has changed from labour to pleasure and hobby activities (Politiek and Bakker J, 1992). The use of horses as farming and forest labour declined with the introduction of tractors and other engine driven equipment, only in Iceland the number of horses has been relatively stable throughout the period, due to the use of horses as transportation in rough terrain. Throughout the 1970's the horse numbers had a low peak in the Nordic Countries, in Sweden to about 70,000 (Herlin, 2007).

Urban citizens settle in the countryside and commute to the working places in urban settings due to the associates between the rural area development, restructuring of the farming sector and the peri-urban relocation. Living in the countryside with a couple of horses is now reality for many people and is the main reason for the increase in the number of horses in the Nordic countries. Figure 3-3 illustrates this trend, the decline in the number of horses in Denmark from 1990 to 1997 can be explained by the recession in the early 1990's. Sweden and Norway have

experienced a 65% increase in the number of horses, but the number of horses in Finland has increased by 50%.

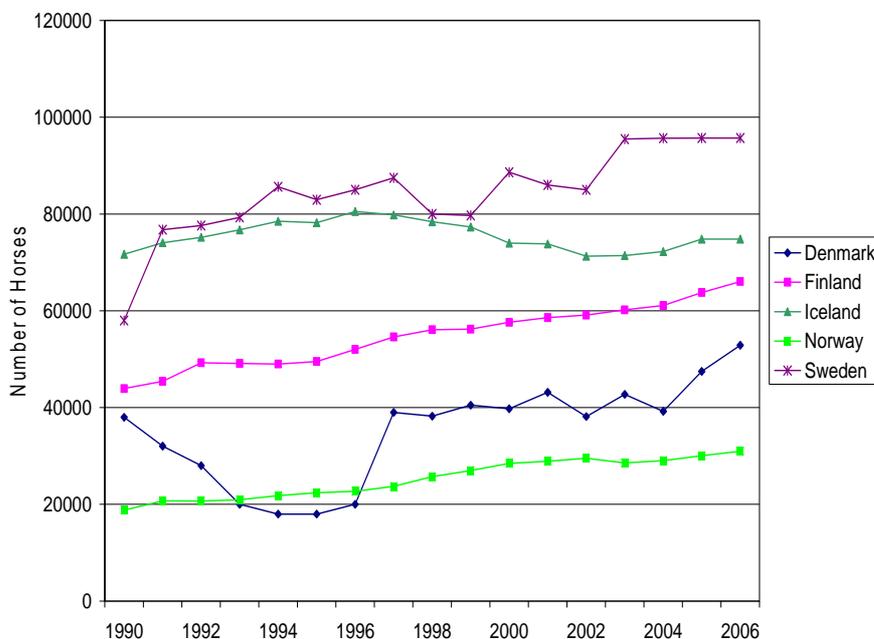


Figure 3-3 Number of horses in the Nordic Countries from 1990 to 2006 [Eurostat 2007]

In Iceland the number of horses doubled over the time period from 1970 to 2006 despite of a small decrease of 4% in the period from 1990 to 2006.

The registration of horses in the Nordic countries is not consistent. It must be emphasized that the figures are very uncertain as many horses are kept on horse farms where it is not required to report the number of animals. Figure 3-3 shows data from voluntary private registration or from a training facility in connection with farms. There are no Nordic countries which register the horses at private residential areas if the properties only are registered as a normal family land register or a business cooperate or as horse farms. It has been suggested that the number of horses in Denmark and Sweden may be more than twice the figures in Eurostat.

The attractive countryside life-style is often dependent on an income from those not living in the countryside; their horses have to stay not too far from their homes. This means that an increasing number of horses are situated in close proximity to urban and dense areas. The use of horses for riding and training in facilities in close proximity to residential areas has by a considerable number of researchers been suggested to pose a health risk as allergens are transmitted to the surroundings (Douwes et al., 2001, Radon et al., 2004a, van Strien et al., 2004). Table 1 shows that Denmark and Sweden have 27.8 and 30.1 horses respectively per 1,000 inhabitants. In some regions close to the northern part of Copenhagen and Stockholm this ratio is most likely to be even higher.

Table 1. The number of horses in the Nordic countries and the number of horses per 1000 inhabitants (Herlin, 2007)

Country	Number of horses	Number of horses per 1000 of inhabitants	Reference
Denmark	174,000	27.8	DST, 2002
Finland	60,185	11.4	NGB, 2005
Norway	42,000	9.1	Committee on farm animal generic resources, 2002
Sweden	283,100	30.1	SCB, 2005

Further information about the interaction between horse related activities, landscape environment in a Nordic perspective has been described by Anders Herlin (Herlin 2007).

Chicken hold in the Nordic countries

The growth and production of chicken are together with pig farming the key source of odour annoyance in the surrounding farm houses. The number of chicken in the Nordic countries has the last few years been relatively constant although Sweden has experienced a 45% drop in the numbers. In reality, the actual number may be slightly underestimated due to notable numbers of chicken at the leisure based farms. (winds are not included in the official statistics) After the avian flu outbreak in Europe during 2001–2004 authorities have initiated registration of all chicken holds. It is assumed that 25% of all smaller chicken holds will be closed down during the next ten years due to public awareness of avian flu. The number of larger chicken operations with more than 100,000 units has not experienced any changes in numbers in relation to this threat.

Figure 3-4 illustrates that the number of chicken in the Nordic countries, Finland, Iceland and Norway has remained constant, whereas the number of chicken in Sweden has declined since 1990. The number of chicken in Denmark is more than half of the Nordic total and varies from 15.5 million to less than 21 million on annual basis.

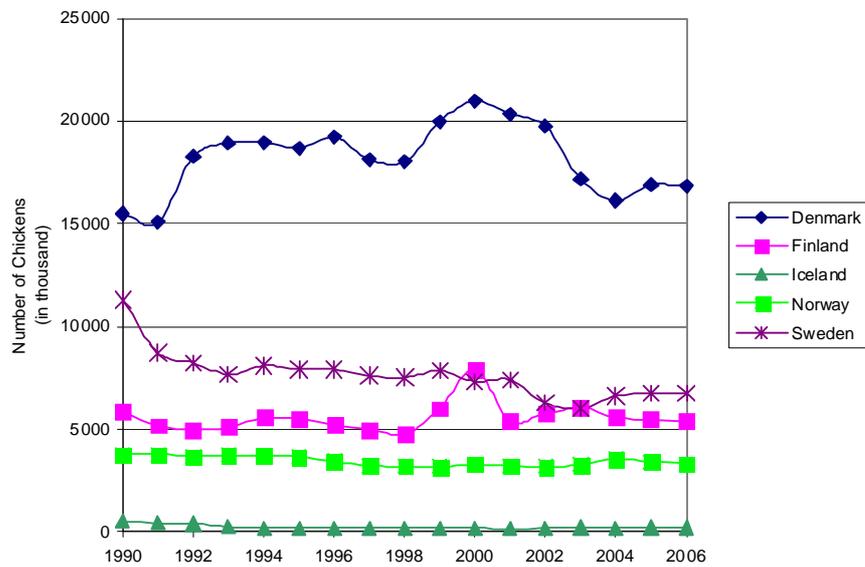


Figure 3-4 Number of chicken (in thousand) in the Nordic countries from 1990 to 2006 [FAO 2007]

Number of cattle in the Nordic countries

The number of cattle in all Nordic countries has declined around 20% between 1990 and 2006 (Figure 3-5) whereas the number of cattle in Denmark has declined by 30% as the largest drop (FAO 2007). The main explanation is the overall decline in meat prices, as well as trade barriers to the biggest market in the US and competition from external markets in the new eastern European countries.

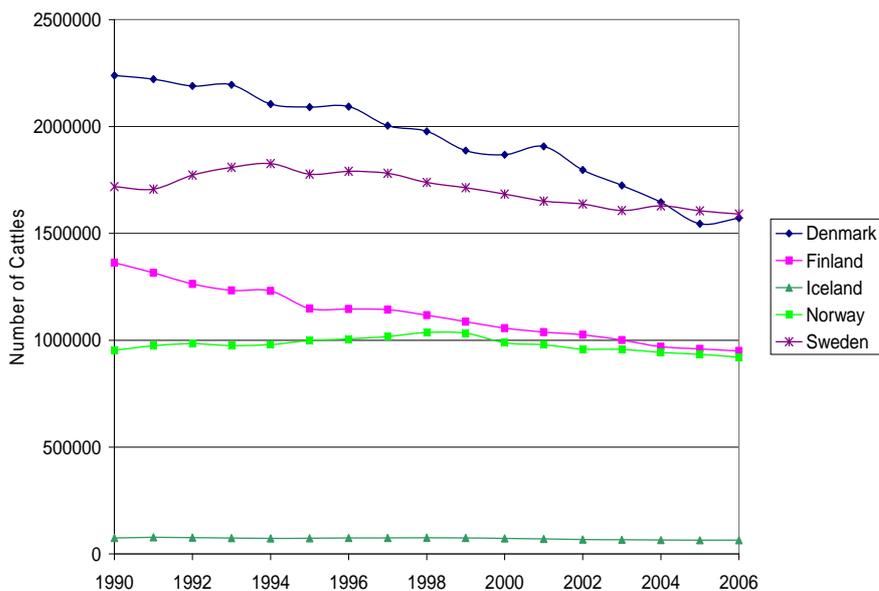


Figure 3-5 The number of cattle in the Nordic countries from 1990–2006 [FAO 2007]

3.3 Number of individual houses in close vicinity to livestock farms

Table 2 shows the number of residencies in Denmark that are placed in the vicinity of livestock farms over a certain size. This selection is based upon the number of Animal Units per livestock farm. Larger livestock farms typically cover an area with a diameter of 100m (radius 50m), and the distances given in Table 1 should therefore be reduced by approximately 50m. Thus about 6,700 residences are placed within 300m from a livestock farm with more than 249 animal Units.

Table 2 Number of private residences in the vicinity of livestock farms in Denmark based on registry data per 31/12 2002 (Steen Gyldenkærne, Policy Analysis, NERI 2005).

Radius (meters)	Size and number of livestock farms	
	>125 DE 6238	>249 DE 963
	Number of private houses	
100	8,708	1,258
150	13,939	1,953
250	28,190	3,983
350	46,548	6,699
500	84,312	12,561
1,000	298,966	53,630

The calculation of residencies that may potentially be affected by livestock farming has been derived from register data and the location of livestock production registry and information on residential areas from the Danish property register. (Det centrale Husdyrregister, CHR-registret). Both the livestock farms and the general property are classified as points. Fur and small leisure animal-holds are not incorporated in the register which only contains animal production.

Approximately half of the livestock production units are piggeries, the other half are cattle holds, thus a larger share of piggeries for the larger productions unit (> 249 animal units). Poultry farming contributes only to a small percentile of the Danish livestock.

4. Health implications regarding airborne exposure from livestock

In general, health problems associated with dust from farming have received little medical attention. After the description of farmer's lung associated with exposure to mouldy hay, most of the attention in this field has been on adverse effects of mouldy and contaminated plant products. Only few of the more than 100 known causes of farmer's lung are related to livestock farming, usually because of contaminated feed that also poses a risk to the health of the animals. Presumably, farmers have generally been more aware of the health risks in relation to their animals than in relation to their own health. Although in the last couple of decades, the health effects of the livestock environment have been extensively investigated, especially but not exclusively in swine, poultry, and cattle farming.

Consequently focus has been on the pattern of livestock exposure which has changed gradually in the last few decades as more CAFO's require longer working hours inside animal buildings. This is not only true for swine production, as mentioned in the first reports of health hazards in CAFO workers from the mid 1970's, but also for cattle, poultry, and almost any other animal species that can be raised on a farm. Today, in many countries, livestock exposure is full time for employed workers on large farms and it is only interrupted by week-ends and holidays off work. The length and timing of the exposure have changed, as well as the exposures themselves. Modern livestock buildings with automated systems for feeding, manure disposal, temperature, humidity, and ventilation contain different and in many cases higher airborne exposures than the traditional farms. Molds on the other hand have probably become much more rare in these settings.

More recently and to a much more limited degree, the possible effects of emissions from CAFO's to the neighbouring environment have been investigated.

Odour and allergens sources in animal farming

The dust in animal housing originates from the feed, the bedding material and from the animals themselves. A small amount enters the animal housing with the incoming ventilation air. The dust particles are carriers of gases, microorganisms, endotoxins and various other substances such as skin cells and manure particles.

Human health impact of airborne exposure from livestock

It is well-known that the environment in swine confinement buildings is a cause of breathing impairment and loss of lung function in farmers due to the airborne exposure from livestock ((Omland, 2002b), (Omland, 2002b), (Omland et al., 2000), (Preller et al., 1995a), (Thorne, (Cormier et al., 1991b)). Acute exposure to high amounts of dust from swine confinement buildings has been shown to induce an inflammation in the lungs called neutrophilic pneumonitis. Furthermore, acute exposure of naive subjects has been shown to induce substantial more inflammation to farmers. Cattle and poultry are also known to cause both short and long term breathing impairment among exposed workers. In addition there are reports about adverse effects on the airways in connection with livestock consisting of sheep and horses. The airway diseases that may relate to livestock exposures include development of allergic and non-allergic rhinitis, other upper airway and mucous membrane irritation symptoms, allergic and non-allergic asthma, aggravation of existing asthma, chronic obstructive lung disease, hypersensitivity pneumonitis (farmer's lung), and airway infections. Allergic alveolitis may be caused by exposure to mouldy hay and may thus be related to, although not directly caused by, exposure to cattle and cows.

A study in Norway regarding children living in rural areas showed a significant inverse association between indoor endotoxin levels and the occurrence of hay fever, atopic asthma and sensitisation (Braun-Fahrlander et al., 2002).

Eduard, W. and other conducted a comprehensive study investigating if the exposure from farming cause or prevent asthma. This study was based on questionnaires from adult Norwegian farmers. The result shows that the prevalence of asthma was 3.7% for physician diagnosed asthma and 2.7% for current asthma. The prevalence of atopy was 14%, but most asthmatic subjects were non-atopic (80%). Compared with farmers without livestock, asthma was significantly higher in cattle and pig farmers and in farmers with two or more types of livestock. Atopic asthma was less common in farmers with two or more types of livestock. Exposure to endotoxins, fungal spores, and ammonia was positively associated with non-atopic asthma and negatively associated with atopic asthma. No associations were found with atopy. (Eduard et al., 2004b).

The role of separate components in airborne exposure from livestock

Allergens, i.e. agents that may cause specific allergic reactions in humans, are abundantly present in livestock environments. These allergens consist of proteins from the animal feed, from the animals themselves, from microbes, or they may to some extent be chemicals and pharmaceuticals used in the animal housing. Specific allergic reactions and diseases (such as allergic rhinitis or asthma) relating to any of these allergens are,

however, not common in livestock farmers and workers although they do occur.

Hypersensitivity pneumonitis or farmer's lung primarily seen in dairy farmers is a rare disease too. Since allergens cannot easily be avoided and the disease rarely disappears once present, many cases of allergic diseases will force the diseased farmer or worker to find another job. Thus, allergens appear to play a limited role in industrialized farming environments. Although it cannot be ruled out that this is partly due to the selection of trade by individuals that tend to easily become allergic (individuals with atopic disposition).

Odour alone has been shown to negatively affect the immune function in neighbouring residents mediated by stress (Avery et al, 2004b) but the isolated effect of odour has not been studied in livestock exposed workers. In experimental settings, odour may cause some of the adverse health effects associated with poor indoor climate (Cormier et al., 1991a).

Importantly, humans adapt rather quickly to odours and tend not to register even strong odours after few minutes of continuous exposure. It is a common belief that odour from swine is worse than from cattle farms and this is supported by the greater emission rates from swine stables in Europe (Takai et al, 1998a).

Gases relating from livestock production, of which ammonia has been widely studied, can reach concentrations high enough to cause adverse health effects. In swine stables, gases evaporate from the manure pits underneath or in close adjunction to the buildings. In most cases with mechanical ventilation, the levels reached both inside and outside are not of concern. In specific situations, such as mechanical malfunction, gases and especially hydrogen-sulphide can reach very toxic concentrations inside the building and in the worst cases cause death. Although most researchers agree that current gas concentrations have limited or no adverse health effects even with long workdays, some studies have found that these gases were not associated with adverse health effects separately from other airborne exposures (Cormier et al., 1991a, Monso et al., 2000).

Exposure to high levels of endotoxins is particularly well documented in many types of farming, but other substances of microbiologic origin such as peptidoglycans and β -glucans are also present at high concentrations. Airborne concentrations of live bacteria are also very high (Duchaine et al., 2000), (Donham et al., 1986), (Attwood et al., 1987a). Gram-positive bacteria dominate this population as they easily represent 90–95% of the total amount of (dead as well as live) bacteria. Endotoxins are capable of inducing many of the symptoms associated with livestock exposure, including fever reactions as seen in organic dust toxic syndrome and farmer's lung and worsening of asthma with cough and breathlessness. Thus, it is not surprising, that endotoxins have drawn much attraction. Several epidemiologic investigations have found that

respirable endotoxins in farming and other environments were closer associated with adverse effects on the airways and immune system than those caused by airborne dust levels.

Most investigators agree that no single component or factor is responsible for the adverse health effects that occur after exposure to the animal farming environment (Cormier et al., 1991a, Monso et al., 2000). Rather it is the exposure to the mixture of gases, dust particles, allergens, microbes and substances of microbial origin that in combination induce the inflammation in the airways and the systemic changes in immune function (Omland, 2002a). The term bioaerosol is commonly used to denote this mixture in ambient air, related to livestock as well as many other occupational environments.

The origins of the bioaerosols are the animals themselves: their feed, stools and urine with some allergens from skin and hair. Additional components stem from insects and microorganisms thriving on the organic material inside the animal buildings (Omland, 2002a, Radon et al., 1999, Radon et al., 2001). Disinfectants and other agents applied to the environment are also present, and may add to the adverse health effects of workers (Preller et al., 1995c). Bacteria that thrive in this environment give origin to high concentrations of bacteria, endotoxins, and other bacterial components in the air. The fungal load in animal houses with concrete floors without litter is likely to originate primarily from outside air (at least this is true for pigs on slatted floors). For livestock raised on litter (e.g. swine or cattle on chopped straw or on shavings) or animals fed on hay (such as horses) fungi probably originate to a great extent indoors. This is important, since fungal spores appear to be closer associated with the asthma prevalence in livestock farmers than endotoxins (more protective in individuals disposed for allergic diseases (atopics) and more harmful in individuals not disposed for allergic diseases (non-atopics)) (Eduard et al., 2004c). Bioaerosols containing this type of components have repeatedly been found to induce lung function changes, upper airway and mucosal inflammation, symptoms and systemic inflammatory reactions in adults exposed to them.

Short term versus chronic effects?

Both short term and chronic respiratory health effects have been linked to exposures from livestock activities. Respiration inside the buildings with swine cause the lung function to fall and increase bronchial responsiveness within minutes of exposures. It takes hours to return to the normal level (Radon et al., 2002). Lower doses may not decrease lung function but still prevent the normal diurnal increase in lung function (Heederik et al., 1990). Nasal, eye and throat irritation and probably inflammation also appear but is less well-documented (Wang et al., 1997). The inflammatory reaction dominated by neutrophil influx into the lungs is also re-

flected by leukocytosis and mainly neutrophils appearing in the bloodstream. Cases of flu-like symptoms are known in connection with high exposure. A number of symptoms are frequently reported by swine farm workers subject to high exposure. Chronic effects may include irreversible loss of lung function and development of chronic obstructive pulmonary disease.

Microbial cell wall components

The human body's ability to detect and recognise pathogens associated molecular patterns (PAMP's) is supported by highly conserved receptors in cell walls. LPS (Endotoxin) is a part of the cell wall of Gram negative bacteria. LPS consists of a highly conserved Lipid A part that is toxic, a variable polysaccharide part consisting of β 1-3 and β 1-6 linked saccharide-chains and a core molecule (Roetschel, 1975). LPS, the pure lipopolysaccharide and endotoxin are used interchangeably (Morrison et al., 1979). The backbone of the cell wall structure of all bacteria consists of peptidoglycans that are also proinflammatory although to a lesser extent than LPS. The third group of microbial origin relating to farming stems from moulds. The β -glucans are a heterogeneous group of glucose structures consisting of a skeleton of β 1-3 glucopyranosyl units and β 1-6 side chains. In aqueous solutions these β -glucans are often insoluble due to helix formations as single double and triple helices. This renders these compounds as rather stable structures that are only recognised by their receptor counterparts on the cellular surface or in the blood stream. Table 2 lists some of the more common β -glucans and their origin. Laminarin from the brown algae is an example of the small glucans (MW < 10,000) that does not initiate the innate immune system. Most of the pro- and antiinflammatory responses of glucans are mediated via a receptor named Dectin-1.

The cells of the immune system features receptors, the so called Toll Like receptors recognising PAMP's, TLR4 is involved in endotoxin recognition and mediation of inflammation by this bacterial compound. TLR2 mediated inflammation is induced by peptidoglycan (Yoshimura et al., 1999; Schwandner et al., 1999). This process has been shown to be augmented by the MD2 protein (Takeuchi et al., 1999).

Children – a vulnerable group?

The effects on children's health are subject to some debate. On the one side there is evidence that the (traditional) farming environment is protective against the development of allergies and some allergic diseases and more so with (varied) animal exposure. On the other side, there is impelling evidence, that high concentrations of modern livestock operations in the close vicinity of children's homes are associated with negative health

effects and increased risk of lung diseases including asthma-like symptoms. Children's exposure is likely to differ from that of adults with less exposure from inside concentrated animal buildings and more exposure to diesel exhaust and feed, grain and other dusts outside these buildings as well as odours. Livestock exposures even appear to be strongly protective against atopy in the prenatal period (Ege et al, 2006). Whether livestock exposures are protective or harmful depends on the genetic background of the exposed person and this is true both in childhood (e.g. (Eder et al., 2006)) and adulthood (Eduard et al., 2004d).

Allergen exposure

Many different allergens of animal and plant origin are abundant in farming. In cattle breeders it has been shown, that even several years after the last animal contact, there are significantly more allergens in the farmer's house, compared to other houses (Nowak). For people having horses, it has also been observed, that their families are exposed to high amounts of horse allergens. This means, that the allergens are stable over time and can be transported from the stables to housing quarters of the farmers or horseback riders themselves. There is only very scarce information on the allergen concentrations in the area surrounding a horse stable or a cow-shed.

Health effect in the surrounding residential area

Several studies on health effects in the residential areas have been conducted in countries outside the Nordic countries. In the Niedersachsen Lung Study poorer lung and more respiratory symptoms, not caused by colds, were observed among residents with more than 12 livestock farms in the neighborhood (Radon et al., 2005) than among those with only 1–5 such farms around.

Differences in technology and climate is, however, likely to cause differences in qualities and quantities of exposures in residential areas. Importantly, it has been shown that whereas bioaerosol components such as gases and bacteria can be traced at long distances from CAFO's, they are diluted to minute amounts within very short distances of the ventilatory outlets (at least under most climatic conditions). However, higher background levels of e.g. endotoxin can be found in rural areas with intensive livestock production than in urban areas (schulze et al., 2006). With the current knowledge of mechanisms there is no reason to think that such low levels could have adverse health effects other than those caused by odour.

Quality of life, as indicated by the number of times residents could not open their windows or go outside even in nice weather, was found to be similar for residents in the vicinity of a cattle operation or far away from a livestock unit but greatly reduced among residents near a hog operation

(Wing and Wolf, 2000). More wheezing has been observed among pupils at schools in the vicinity of confined swine feeding operations (Mirabelli et al, 2006).

4.1 Characterisation of odour

Odour can be characterized by concentration, intensity, persistence, hedonic tone and character. The odour concentration, which is a multiple of the concentration detection level measured with the help of a panel and an olfactometer diluting the odour sample can be measured in for example, the European odour units (OU_{EM^3}). Odour measurement using electronic noses still cannot be considered as an alternative to olfactometry. The odour intensity refers to the perceived strength of the odour sensation and may be described by a logarithmic expression. Odour intensity is often based on the intensity of a reference gas such as n-butanol.

Odour impact on life quality and health

Odour can potentially have an effect on human health. Susanne S. Schiffman suggests four ways that odour could have a potential human health effect. The VOC themselves could pose toxicological effects though odorant compounds could cause sensory irritation in the eye, nose and throat.

Human perception of odour varies due to the understanding of the human response to odour and its importance for human life quality and health. It is of major concern in the control of malodours from the livestock farming (Schiffman et al., 2001; Verein Deutscher Ingenieure, 1994). Psychological and social factors influence the human perception of odour response (Nimmermark, 2004b). Odour may have positive as well negative effects on the well-being of human beings dependent on the type and concentration of odorants.

There are more than a 1,000 different receptors, each reacting to a specific group of odorous compounds. Different combinations of interactions between several receptors at the same time mean that the human brain can differentiate between more than a 10,000 odours. There are individual differences in the human perception of odour. Perception is not only biologically determined but also culturally influenced and depending on the circumstances.

The human sensitivity towards the perception of an odorous compound can differentiate up to a factor 1,000 (Nimmermark, 2004a). When the level of odour annoyance in the neighbourhood of an odour source is assessed, the frequency and the duration of odour play a key role. Intermittent fugitive odour sources are difficult to regulate and control. Inves-

tigations of the odour emission and annoyance arising from spreading slurry in the field are used as a base for further guidelines.

Definition of odour annoyance

An odour is perceived when odorants interact with the sensory receptors in our noses. There are five different receptors of neural systems localized in the nasal chambers of humans: 1) The main olfactory system, 2) the trigeminal somatosensory system, the so-called common chemical sense, 3) the vomeronasal system (VNO), 4) the terminal nerve, and the septal organ. (Nimmermark, 2004c).

Annoyance is a subjective condition of discomfort caused by substances or circumstances which, in the opinion of those personally affected, can have negative effects on the individual or a group of people (Verien Deutscher Ingenieure, 1997). The VDI in Germany has drafted guidelines which serve as decision making recommendations on how to define and enforce odour annoyance. The guidelines describe investigation methods to determine any existing or possible annoyance due to odour intensive substances.

Health summary

Current asthma was most often found in cattle and swine farmers. Non-atopic asthma is positively associated with exposure to endotoxins, fungal spores and ammonia. Further studies have suggested that a possible effect of exposure to endotoxin observed during early life may occur in adults with high occupational exposure. Exposure to other agents such as fungal spores may also be involved.

5. Bioaerosol sampling

The air in livestock buildings contains bioaerosol levels that are sufficiently high to cause adverse health effects in animals, workers and people living in close vicinity to concentrated animal feeding operations and to a certain extent outdoor horse holds. When evaluating the health effect of bioaerosols, their composition, concentration and measurement methods applied must be considered.

Bioaerosols are complex mixtures of living and dead micro-organisms and their products as well as other aeroallergens. The effectiveness of sampling methods used for quantifying the very high concentration or micro-organisms in these environments has not been well studied. To facilitate an accurate assessment of respiratory hazards from viable organisms in agricultural environments an overview or current bioaerosol sampling practise is needed.

Various devices for assessing airborne concentration of viable micro-organisms have been developed and evaluated over the past decades (Thorne et al., 1992). The all glass impinger method (AGI) was introduced in the 1920's and modified in the 1950's and a widely used method. This device is inexpensive, easy to use, and it allows for sampling at a considerable range of ambient concentrations when a serial plating of the solution is performed. In addition, a single sampling solution can be plated onto a variety of media plus subjected to chemical tests or toxin analyses. Limitations of the AGI were noted as loss of viability due to impingement of the micro-organisms. In addition, some organisms may suffer from the effects of sudden hydration upon impingement or osmotic shock. Viable sampling must be performed for short periods of time, less than about 30 min, and preferably on ice to impede replication of microorganisms.

The six-stage Andersen microbial sampler method (AMS) was developed to allow simultaneous sizing and counting of viable microorganisms. The AMS has been studied in detail by a number of researchers, and improvements in the design and in the colony enumeration techniques have been performed over the years. Other studies have tested the use of the six-stage AMS in alternate configurations with just the last stage. Today six stage, two stage, and single stage AMS are sold commercially and these configurations are widely used. The AMS has the advantage that the collections take place directly onto a culture media for incubation and analysis with no further dilution or plating. The main problem associated with the AMS is that one can only sample for viable microbes, and many of the organisms may not be viable but still have harmful effects when inhaled. Another major problem is the rapid over-

loading of the plates that occurs at high levels of organisms. An approach developed for expanding the sampling range of the AMS was to homogenize the agar after sampling and to plate serial dilutions to establish total viable counts. This technique, however, can decrease the viability of the many organisms and suffers from the same drawbacks as other serial plating methods. Other potential problems with the AMS are agglomeration of microorganisms, the stress of impaction, and electrostatic attraction of particles to the plastic agar plates.

Collections of airborne micro-organisms onto filter media followed by elution and plating were studied by Wolochow in 1958 and found to be suitable for some organisms within certain environmental limits. Major problems with this membrane filter method included loss of viability and poor recovery of the organisms from the filters. Later studies indicated that this method was a reasonable way to sample for microorganisms, given the minimal equipment needed and its suitability for a variety of environments.

Initial studies with membrane filters indicated that microbial recoveries are lowered as a result of trapping in the filter matrix. In comparative studies, Lundholm has found that the membrane filter methods give consistently lower recovery that varied with the test environment (Thorne et al., 1992). The polycarbonate filter has been available since 1975 and this method offers standardized pore size combined with a smooth surface to allow better retrieval of the microorganisms. Palmgren et. al have developed a method for evaluation of aerosolized microorganisms and used it extensively for studying agricultural dusts in Sweden. Use of the NFE for viable organisms has shown that there is as much as a fourfold loss of viability, especially for spores. Despite variable results with this method in comparative studies, filter methods continue to be used due to simplicity and their ability to provide information on both viable and nonviable organisms (Thorne et al., 1992).

The realization that methods developed for bioaerosol sampling in other settings does not necessarily work well in the agricultural environment. Therefore samplings of bioaerosol are often undertaken in order to systematically evaluate in conjunction with an exposure assessment of swine confinement workers. Peter S. Thorne and others have evaluated the three previously mentioned approaches in bioaerosol sampling methods in order to facilitate an accurate assessment of respiratory hazards from viable organisms specifically with focus on the agricultural environment.

Sampling personal bioaerosol exposure

Various sampling techniques have been developed in order to quantify the individual exposure of airborne biological agents. One of the methods is a personal bioaerosol sampler named the CIP 10-M (M-microbiologic). The CIP 10-M has been developed for measuring occupational exposure

to biological agents. This sampler is battery operated; it is light and easy to wear and offers full work shift autonomy. It can sample much higher concentrations than e.g. biological impactors and this type of sampler limits the mechanical stress on the microorganisms during the sampling. Biological particles are collected in 2 ml of liquid medium inside a rotating cup fitted with radial vanes to maintain an air flow rate of 10 l min^{-1} at a rotational speed of approximately 7,000 rpm. The rotating cup is made of sterilisable material. The sampled particles follow a helicoidal trajectory as they are pushed to the surface of the liquid by the centrifugal force, which creates a thin vertical liquid layer. Sterile water or another collecting liquid can be used. Three particle size selectors allow health-related aerosol fractions to be sampled according to international conventions. The sampled microbiological particles can be easily recovered for counting, incubation or further biochemical analysis, e.g., for airborne endotoxins. Its physical sampling efficiency has been laboratory tested and field trials have been carried out in industrial waste management conditions. The results of these laboratory tests indicate a satisfactory collection efficiency, whilst experimental application has demonstrated the usefulness of the CIP 10-M personal sampler for individual bioaerosol exposure monitoring.

5.1 Measurements of odour

In an air sample the contribution from individual odours' substances can perform as an odour cocktail where each odour agent do not enforce additive odour effects, but may be enforcing or annihilating each other. In that respect, odour cannot at the moment be measured with conventional types of instruments as used for chemical components, until now the human sense of smell has been used. When authorities enforce environmental regulation of odour, the scale and odours impact of the individual odorous components is in general not known.

The sensory evaluation of odours' air from livestock houses and the application of animal manure are to be divided into determination of odour concentration on the one side and odour intensity on the other side. The perceived odour intensity means how strong an odour smells. In the frame of the EC-program, COST 681, scientists have outlined "recommendation on Olfactometric Measurements" (Hangartner et al., 1989).

Odour measurement technologies

The odour concentration can be measured in Odour Units [OUE] after DS/EN standard 13725. 1 OUE corresponds to the amount of odorous compounds evaporated in 1 m^3 air which gives a response (50% criteria)

from a human sensory panel corresponding to 123 µg n-Butanol¹. The classical method of measuring odour is through the use of olfactometry.

For that purpose an instrument called an olfactometer is often used. It produces a series of dynamical dilutions of an odorous sample, which are presented for a sensory panel. The panel consists of trained people with an olfactory sense in the normal sense range. The panel estimates a given dilution of an odour sample up against a clean air sample as reference point. They start with the most diluted samples, where a difference between sample and clean air is not possible to detect. The sample is diluted less and less, and gradually an increasing number of the panel members are able to point out the odorous

The chemical analysis of volatile compounds from animal units is mostly done by use of Gas Chromatograph – Mass Spectroscopy). The chemical composition of the air in the animal housing, which is exhausted into the surrounding of the facility, is based on the findings with this technique. An electronic nose is an instrument with differential chemical sensors for volatile compounds. The electronic nose has been developed in various applications used in different odour experiments.

Olfactometry

Determination of odour concentrations by the use of the human sense of smell is called olfactometry. The method is based on the use of a nose-panel; often it consists of 6 people in the laboratory who are exposed to an odour sample, diluted by varying amounts of clean air. The situation is defined as the odour threshold when half of the panel is able to detect an odour while the other half cannot; the dilution then has a concentration of one odour unit per cubic meter (OU/m³). The original concentration can then be determined from the dilution ratio. The European standard EN 13,725 described the method in detail. The method only works for samples with high concentrations. The method has a relatively high uncertainty, which may be reduced by repetition. (Oxbol, 2004).

Dynamic dilution olfactometry is still currently the accepted standard procedure in the odour measurements, whereas, a chemical substance is not found. Besides determination of the odour concentration, sensory methods have been developed for the level of annoyance or nuisance caused.

The odour nuisance has no direct relation with odour emission and concentration. The nuisance must be measured with appropriate techniques based on population panels. This method is complementary to the dynamic olfactometry. In Europe, the most widely accepted method for odour annoyance is the VDI guideline 3,882 (Verien Deutscher Ingenieure, 1994). This method characterizes levels above odour threshold

¹ European Reference Odour Mass = EROM

with the help of a scale of eight categories from extremely unpleasant to extremely pleasant.

Field measurements

The main source of data for verification of models is to maintain and study field measurements. Many dispersion models are validated on concentration measurements from full-scale field measurements.

Routine monitoring of concentrations normally takes place at only few locations. For typical routine monitoring, the pollutants measured cannot be uniquely ascribed to a single source, so the source term may be uncertain. These facts limit the usefulness of routine data. However, an advantage of routine monitoring is the long term series of measures, covering a broad range of different meteorological conditions.

Intensive campaigns are typically short with duration of a few days or weeks, where experiments are conducted only during a limited number of hours. The spatial resolution of concentration measurements can be high.

Intensive experiments are normally performed by measuring tracers' concentrations downwind or a source. The sources can be existing single point sources, several outlets on complex building or artificially constructed sources. The tracers can be component as NO_x or NH₃ released from the source in focus. It can also be an added artificial tracer such as inert gases or smoke, consisting of small particles. The artificial tracers often have a negligible deposition velocity. In any case, the existing background concentration must also be assessed and accounted for, which can be a majored source of uncertainty (Olsen et al 2005).

5.2 Regulation of odour and bioaerosol emission

The odour levels from livestock, especially from pig production, are normally consider as an annoyance in the surrounding residential areas and not by the farm industry. Residential communities have a common demand on the bare minimum odour annoyance.

Odour regulation can be achieved by reducing emissions from stables and related productions units or by diluting indoor air quality before releasing it to the outdoor air. Any lowering of the emission will be a benefit for both odour annoyance as well as dispersion of bioaerosols.

Lowering odour annoyance and/or evaporation of odours' components is both benefiting indoor as outdoor air quality, but also reducing the exposure of air toxins which are associated with the manure (Kai, 2005).

Bioscrubber or airsubber is a well-know method to reduce odours components from the industry. The method is based on leading polluted air through a porous substance, as constant sprinkles with water where the odours component in the air absorbers by the water. The concentra-

tion ratio between the two phases is causing absorption, where the absorbed odours component in the water is removed by biological or chemical oxidation (Takai et al., 1998b). Different types of bioscrubbers have been developed where biofilters have shown to be a useful alternative to the chemical filters, thus the capacity are limited in comparison with standardised bioscrubbers (Kai, 2005).

Both combustion and chemical oxidation are useful in order to reduce the odour. The combustion process is relatively expensive because it demands a steady temperature of 700 degrees C if the combustion should be ideal. The use of a catalyser can reduce the combustion's energy demand and consequently reduce the energy costs.

Another method to reduce odorous emission from livestock production is by absorption. Absorption is a result of surface activities on various components, e.g. surface of carbon. Absorption has the ability to restrain air pollution components which immediately have contact to carbon matters' surface, the size of the surface is the driven force for filtering an odour's component out of a given air mass. The method restrains the odour's component in filters, which frequently must regenerate in order to remove the odour's component. The relative large dust fraction occurring in the many indoor stables or farming houses have a tender to block the filters (Kai, 2005). In that respect, the method is not ideal for larger concentrated animal feeding operations.

UV irradiation has been tested as a method to eliminate odours component in an air parcel, theoretically the UV irradiation will eliminate the organic fraction of the ventilated air mass. Due to the health risk, UV irradiation is posing to the livestock and the farm workers, the method can only be used in the plume emitted from the livestock operation. The detention time in the emitting odours' parcel is consequently too short in order for the theoretical UV irradiation approached to work acceptable.

Various Best Available Technique (BAT) have been discussed and can be found in literature (Arnold, 2006; Eder et al., 1994, Kai, 2005; Løftstrøm et al., 2006; Nimmermark, 2001; van Strien et al., 2004).

Buffer zones as mean to reduce odour annoyanc

Buffer zones are environmental management planning tools intended to protect sensitive areas from negative environmental impacts. Establishing buffer zones from livestock production and neighbouring residential areas have been created in order to dilute the emitted odours' fraction and minimize the odour annoyance. The buffer zones has induced the development of various integrated empirical models in order to suggest an appropriate distance between livestock and residential areas. The planning methodology include the size and number of animal holds, bedding material, temperature and design of stables and types of stacks.

Switzerland developed buffer zone guidelines in 1988 (Koller & Schmidlin, 1998). Germany introduced standardized methods for poultry and pig production in 1993 (Verien Deutscher Ingenieure, 1994). In 1994 Austria implemented buffer guidelines where meteorological conditions around the livestock operation are integrated (Eder et al., 1994).

Some of the early developed buffer zone calculations was not harmonised due to different standards for plume velocity, variation in building design and manure storage. It is recommended to incorporate modelling of odour and also investigate the risk potential for dispersion of allergens from the livestock operations.

Handling storage of manure

The manure is the key component of odour emission from all livestock, and the simple role of quickly removal of faeces and urine will limit the evaporation and dispersion of odour components and will limit the microbial, and the bacterial growth inside the stable. A research project has shown that the flushing system, where manure has been flushed in an hourly interval into separate storage tanks has reduced ammonia emissions by more than 50% (Nimmermark et al., 2005). By storing the manure in aerobic tanks the ammonia emission will be reduced supplementary. The aerobic environments inhibit the formation of odour component produced from the anaerobic decomposition of organic matters. The aerobic environment can absorb large quantities of ammonia.

The hedonic tone can be abridged by reducing the evaporation of odorous substances or by filtering the air before releasing it to the environments. The design of the stables and the manure handling system are parameters which have an important impact on odour regulation.

6. Modelling tools to determine the odour annoyance and dispersion of allergens from livestock farming

Atmospheric dispersion models can be used to assess levels of odour in the surroundings of the sources. The models are important tools in the environmental impact assessment when various strategies to reduce odour are compared and evaluated. Many of the applied models used in odour modelling were developed for the atmospheric dispersion calculation in general, and are not specifically designed to address odour problems.

Operational metrological air quality model

The dispersion of odour is calculated by the Danish developed Atmospheric dispersion model, the so-called OML (Operational metrological air quality model). The OML model is used for regulatory applications by the Danish authorities in relation to handling and regulating odour problems in the agricultural sector and exists as an operational computer program. The OML model is comparable to AERMOD and ADMS, evaluation studies include those of Berkowicz *et al.* 1988, Olsen *et al.* 1992 and Olsen 1995.

The OML model is a Gaussian plume model developed to calculate dispersion of non reactive air pollutants from point and area sources. The model is preferably using locally metrological data in order to incorporate turbulence and local wind condition, the modelled calculated hourly mean concentration's value. The OML model is using continual description of the atmospheric turbulence which is contradictory to other dispersion models. The model is designed to incorporate plume behaviour, building effect, stack's ventilation and inversion as well as systematically changes in wind direction.

The OML model is designed for regulatory use. This means that the degree of complexity is limited.

In 2006, many of the parameterisations in OML have been improved in a new research version that in time also will replace the current regulatory version.

The main characteristics the research version of the OML model are:

- new methods for calculation of plume rise;
- modification of turbulent dispersion due to plume rise;
- special treatment of penetration processes;
- special treatment of plume lofting effect (lofting: as a result of plume rise, the plume may remain close to the top of the boundary layer)
- special treatment of horizontal dispersion in the case of light
- wind conditions or systematic changes of wind direction;

The OML model is designed for short range dispersion in urban and rural environments. The OML model includes methods to account for hilly terrain; however, the terrain correction methods are crude and can only be applied in slightly hilly terrain typical for, e.g., Danish conditions. (Olsen et al., 2005).

The use of OML in odour modelling

The OML model is using receptor calculation when scheming concentration of odour. The receptor points are often placed in 15 spheres with different diameters, and calculation is usually performed for an annual period. The hourly mean 99% fractile is calculated for each month and for each receptor point. The 99% fractile in any given receptor point is equal to the 7–8 highest hourly mean concentration of the monthly 720 hourly values (30 days). In other words, there are only 7 hours in each month where the concentration is higher than the 99% fractile. From the 12 monthly 99% fractile the estimated maximal is monthly 99% fractile estimated in each receptor point (Olsen et al., 2005).

OML odour calculation for different types of sources

The OML model is able to handle multiple point and/or area sources. We will here give an example of a calculation for two types of odour sources, a tall stack (80 m) and a low stack (10 m), the latter influenced by a nearby building shows the concentration distribution function for the two sources (Løftstrøm et al., 2006).

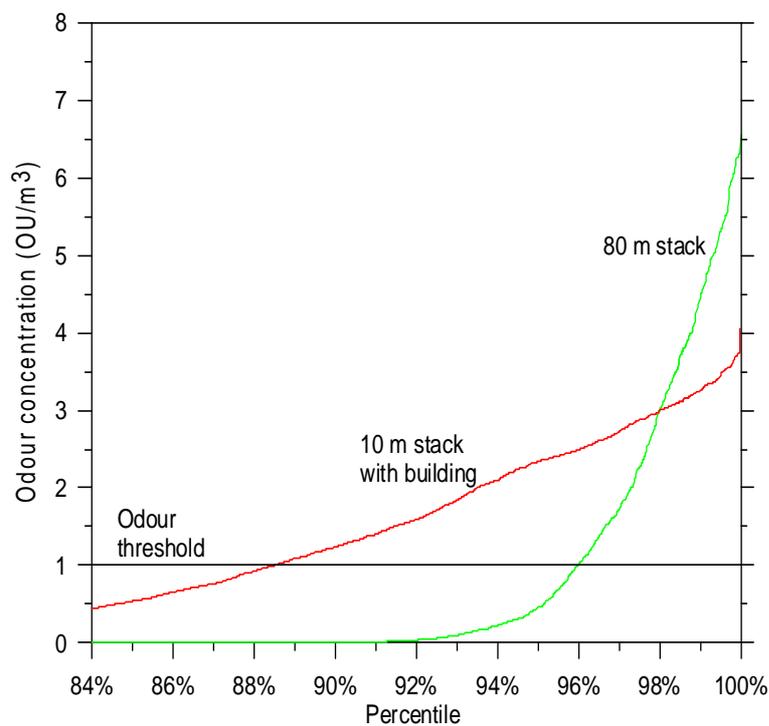


Figure 6-1 Odour concentration distribution function calculated for two different types of sources. For each source, the emission is fitted so that the highest yearly 98-percentile is 3 OU/m^3 . Source data: Tall stack 80 m high, diameter 2 m, temp. 100°C exit velocity 8 m/s, on building and low stack: 10 m, 0.25 m, 20°C , 8 m/s and a 10 m high adjacent building. The location for the highest value is for the tall stack 1,300 m downwind and for the low stack 25 m.

The emissions from the artificial sources are fitted to match a yearly 98-percentile of 3 OU/m^3 at the receptor with the highest 98 percentile, that for the specific case is in a distance of 1,300 m, respectively 25 m downwind of the tall and the low source. It is evident that the tall source has larger concentration values than the low stack for percentiles above the 98 percentile and the opposite is the case for lower percentiles.

The frequency of odour level above 3 OU/m^3 is the same for both sources, but the frequency of odour levels above 1 OU/m^3 is about 3 times larger for the low source, indicating different kinds of annoyance to people although the sources comply with the same limit value (Løftstrøm et al., 2006).

Models for concentration fluctuations

The time resolution of most dispersion models is one hour. However, within a single hour odour varies significantly. In the OML-model, this is handled by applying an empirical relation between the hourly 98 percentile and the short term extreme value. Another approach is chosen in the model developed at the Finish Meteorological Institute (FIM).

The odour dispersion model developed and applied by the Finnish Meteorological Institute (ODO-FMI) differs from other dispersion models by its capability to represent the short-term peak values of the concentrations of odorous compounds, which may vary with time scales less than one minute. The commonly-used hourly mean concentration is not adequate for describing the presence of odour (Hanna, 1986). The concentration of odorous compounds may exceed the odour threshold level, despite the fact that the hourly mean is clearly below the odour threshold (figure 6-2).

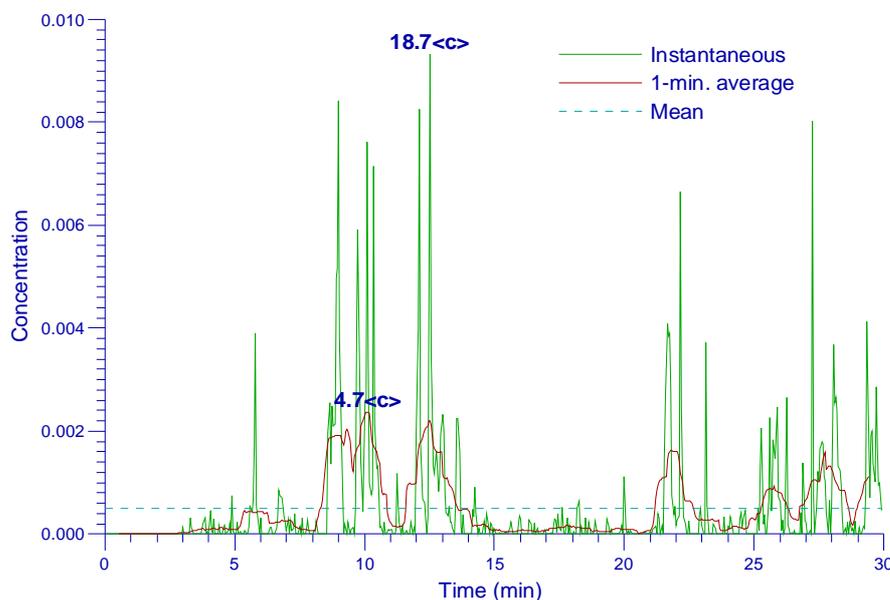


Figure 6-2 The odour concentration exceeds the odour threshold several times despite the hourly mean being below the threshold

The ODO-FMI produces a time series of peak concentrations for each one-hour period. Ultimately, the time series are used to calculate the relative duration of odour as the number of times a specified threshold concentration has been exceeded. The dispersion model estimates odour frequencies as a percentage during one year and the areal distribution of these frequencies. The ODO-FMI can be used to estimate the short-term peak values of odorous compounds from point, area or volume sources. The emissions may vary in time. Both horizontal and vertical fluctuations of the plume are considered in the model. The model has been applied to provide dispersion estimates of odorous compounds for numerous domestic industrial and municipal facilities e.g. waste water treatment plants, landfills, pulp mills, chemical factories, livestock production units and ports.

The odour dispersion model ODO-FMI

The main feature in the ODO-FMI is to assess the concentration fluctuations caused by atmospheric turbulent diffusion. The ODO-FMI comprises two computational methods: the so-called meandering plume method for point sources and the internal fluctuation method (probability density function modelling) for area and volume sources (Hanna, 1986) (Figure 6-3).

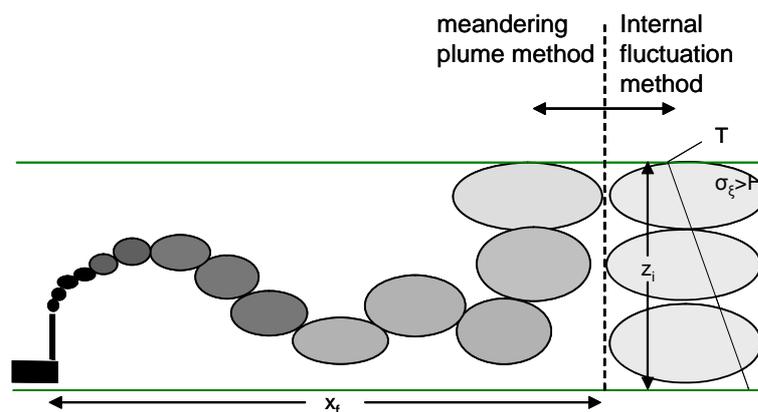


Figure 6-3. Schematic picture of the region of plume dispersion methods in the ODO-FMI. In vertical direction in distance x_i from a source the plume is reaching upper limit of mixing height.

The meandering method describes concentration fluctuations due only to the meandering of the plume. The total standard deviation of the meandering is described by the instantaneous standard deviation and the standard deviation of the meandering motions. In the internal fluctuation method it is assumed that the variance of the concentration is formed with respect to the mean flow both horizontally and vertically by the same kind of diffusion as the mean concentration field.

The model is based on the assumption that the concentration time series due to the meandering of the plume can be represented by half-minute periods in one-hour sample. Each of the half-minute concentration values is assumed to correspond to the position of the axis of the plume with reference to the average airstream in both horizontal and vertical direction at each of the points around the source (Fig. 6-4) (Beaman, 1988).

The fluctuation of the plume axis is assumed to follow a normal distribution. To determine the short term odour nuisance, one must calculate the 30-second maximum concentration during one hour. This can be done either by the definite probability method or by the Monte-Carlo method. When the plume has spread and dispersed so widely that it reaches the upper limit of the mixing layer, the internal fluctuation method is used. The peak concentration is determined by a probability density function, which follows a log-normal distribution.

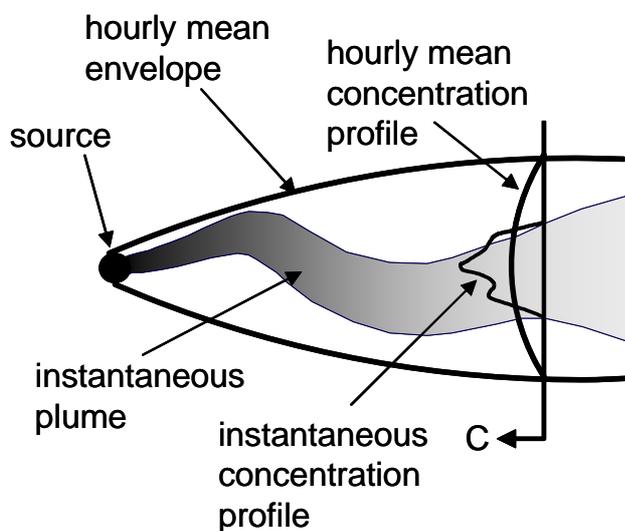


Figure 6-4. Schematic picture of plume meandering from a point source in horizontal plane.

The model contains calculation methods for area and volume sources for describing dispersed releases. In these source types it is assumed that the emission release has already dispersed at the beginning so widely that the internal fluctuation method can be used.

Before calculating the instantaneous (30-second average) and the mean (1 hour average) concentrations needed in the model, the corresponding dispersion parameters and the dispersion of the plume axis have to be determined. Högström's method (Högström, 1972) is used to calculate the instantaneous dispersion parameters and for the dispersion of the plume axis. Determination of the dispersion parameters required in the calculation of average concentrations is based on research on boundary layer meteorology (Karppinen, 2001; Wratt, 1987).

Peak concentration caused by the effect of several sources together can be estimated in the odour dispersion model by so-called background method or by the Monte-Carlo method. In the background method it is assumed that the hourly mean concentration caused by each source makes up the background concentration due to the other sources. In the Monte-Carlo method it is assumed that each source discharge, during the one hour sampling period, instantaneous concentrations (30's average time), which are independent of any other sources, following, however, a certain probability distribution. The portion at each receptor point is calculated, and then combined in order to form a time series of concentrations where the maximum concentration is then chosen. Step by step the UDM-FMI calculates the hourly mean and peak concentrations using the corresponding meteorological and emission situation until the whole meteorological period (usually at least one year) has been employed. The time series are used to calculate the relative duration of odour as the number of times a specific threshold concentration has been exceeded. The odour dispersion model estimates odour frequencies as a percentage during one year (nor-

mally) and the GIS tools are employed to produce the areal distribution of these frequencies. The schematic picture of the ODO-FMI is presented in the Figure 4.

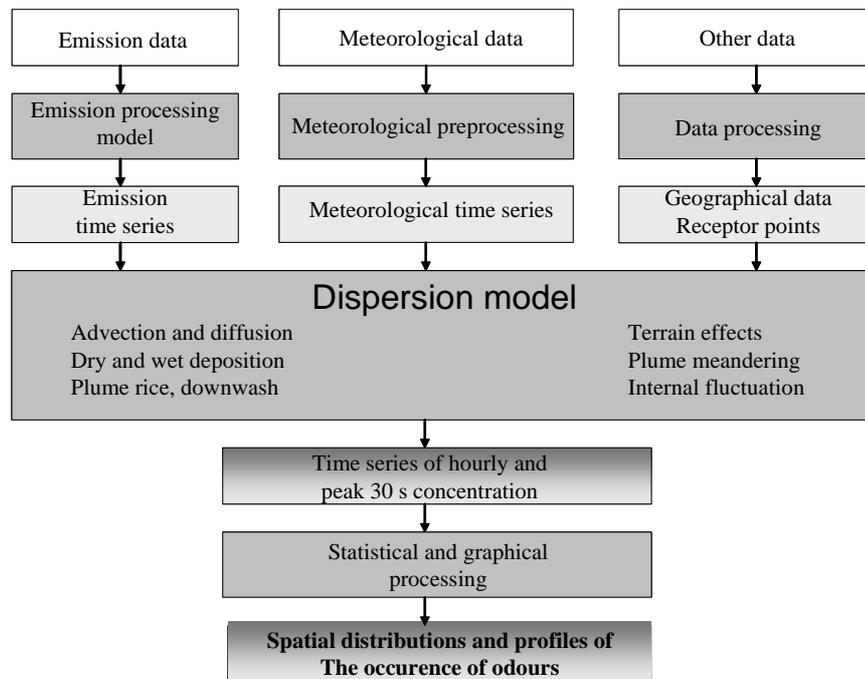


Figure 6-5. Schematic picture of the odour dispersion model ODO-FMI.

The odour emission data required by the UDM-FMI is the amount of odour emissions per time unit. The odour emission can be estimated either by the olfactometric or by the standard emission measurements. The emission can be described in the model either by odour units (ou/m^3 , ou/s) or by mass units (g/m^3 , g/s).

Odour emissions

The livestock farming application of ODO-FMI was applied during the project *Reducing Odour Annoyance from Livestock Farming (2006)* to study the odour emissions of two different pig and poultry production units in Southern Finland (Arnold, 2006). All major emission sources of the production units were considered including the ventilation stacks and the slurry storage. The model calculations were made for the present situation and for few diverse future scenarios with the odour emission reduction techniques in use. Three different odour reduction alternatives studied were; covering the sludge ponds, reducing the number of stacks (from 38 to 7) by merging them together and increasing the height of the stacks by 1 meter. The third alternative was to assume both odour reduction techniques being used.

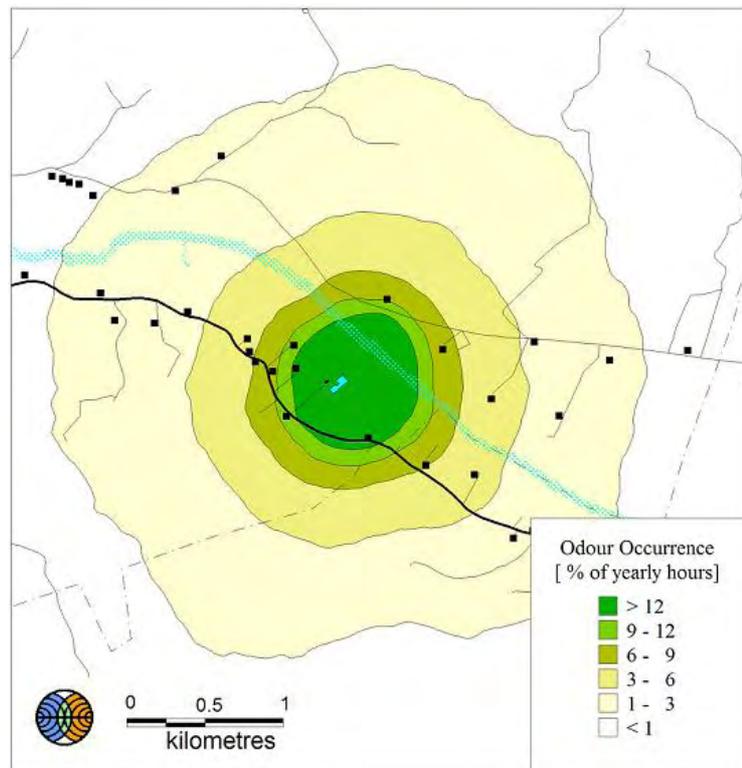
The olfactometric emission measurements were carried out by VTT (Technical Research Centre of Finland) to estimate the emission factors and the seasonal emission variation (Arnold, 2006). The hourly emission time series for individual emission sources were produced based on the emission measurements and the technical information of the sources. The future emissions for different alternatives were evaluated based on the technical specifications of alternative solutions. The emission height and other relevant technical parameters of the emission sources were taken into account in the calculation. The total average odour emissions of the largest studied farrow pig production unit (850 sows) were between 180–1,450 million ou/h depending on the season.

Uncovered slurry storage (manure tanks) contributed 24–58% and the covered manure tanks 1–17% of the total odour emissions in studied pig production units.

Modelling results

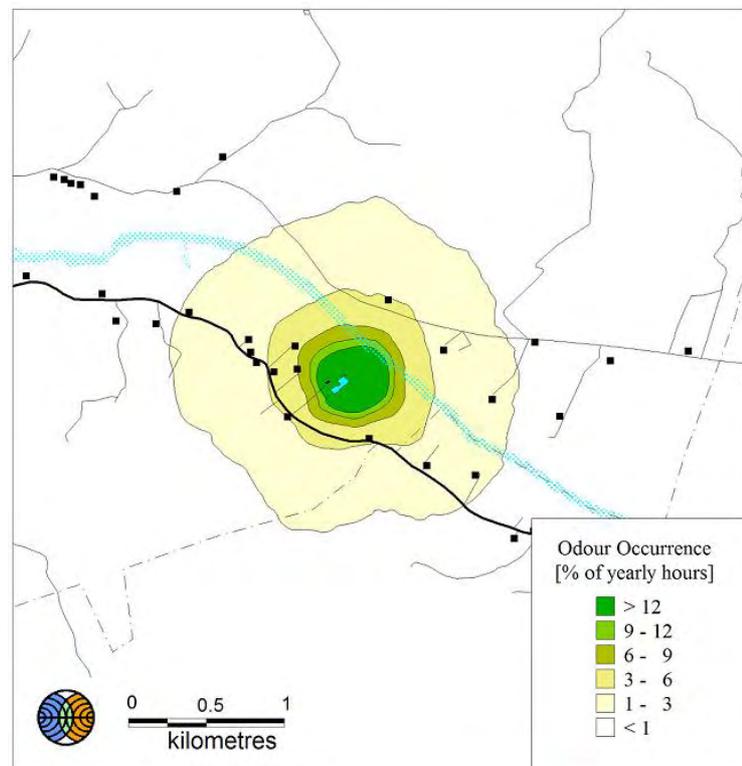
The model calculation results are represented as odour nuisance levels in areal distribution maps. The odour occurrence was calculated for both short term (30's) and long term (1 hour) time scales with different odour thresholds (1.3 or 5 ou/m³). Fig. 6–6 presents the short term and long term odour occurrence with the odour threshold 5 ou/m³ as percentage of the yearly hours. In the nearest surrounding area of the production unit the odour occurrence levels are above 12 % of yearly hours. The odour occurrence levels are decreasing as the distance from emission sources is increasing.

The study showed the contribution of slurry storage on the total odour load. Covering the manure tanks seemed to be the most effective way to reduce the odour load from production units. According to modelling calculations reducing the number of ventilation stacks and increasing the height of the stacks by 1 meter, it did not seem to have a significant effect on reducing the odour annoyance. In fact it seemed to increase the short term odour occurrence a bit further away from the production unit.



Finnish Meteorological Institute 2003

■ = production unit



Finnish Meteorological Institute 2003

■ = production unit

Figure 6-6. The short term (above) and long term (below) odour occurrence levels around the farrow pig production unit (850 sows) with odour threshold of 5 ou/m³.

Model results vs. neighbourhood survey results

ODO-FMI model results have been validated by comparing the modelling results to the results of odour panellist surveys in various study cases. The modelled odour frequencies have been compared with the odour annoyance survey results in the surrounding area of the studied production units also in the project *Reducing Odour Annoyance from Livestock Farming*. The used odour panellist data is not statistically defined in the same way as the modelled data. Thus the comparison with the experimental data is only suggestive. The results of odour modelling calculations were well consistent with the experimental odour annoyance data.

Modelling summary

The odour dispersion model of the Finnish Meteorological Institute ODO-FMI is a usable tool when the odour nuisance levels in the surroundings of a point source, as a livestock unit, are investigated. The model is also an effective tool in the environmental impact assessment when the alternative solutions for odour reduction techniques and methods are compared.

The ODO-FMI differs from other dispersion models by its capability to represent the short-term peak values of the concentrations of odorous compounds, which may vary with time scales less than one minute. Thus, with the model it is possible to predict both the short and long term occurrence of odour. The odour frequency values calculated by the ODO-FMI can be compared with the different guidelines and recommendations given in different countries for odour occurrences. The odour frequencies computed with our model have been compared with experimental data. The comparison shows that the odour dispersion model is well compatible with the experimental results. The odour dispersion model has also been applied to estimate the odour influence of e.g. food production and chemical plants as well as pulp mills and waste water treatment facilities.

7. Livestock farming policies

The increased focus on odour problems related to the agricultural sector is forcing national authorities to consider and, in some cases, implement odour policies and guidelines in regions with concentrated animal feeding operation. As described previously in this report, the intensified livestock production in Denmark has led to various guidelines and policies in order to reduce annoyance and health effects related to the agricultural emission. In Denmark, the regulation of a potential odour annoyance from the livestock production is accomplished by distance regulation. Further regulation on manure handling and storage has reduced the dispersion of odour as well.

7.1 Nordic Regulation

At present, there is no international odour threshold limit value because no standardised method has been developed for assessment of odour annoyance. Limit values are typically based on concentration levels where the odour dispersion must be applied for a certain period of time normally an hourly value. Due to variation in national nuisance standards for odour, it is a difficult task to imply unambiguous Nordic standards.

Typically, a limited value must not be exceeded more than a certain percentage of an hour according to the current regulation.

The thresholds are guiding, due to the fact that many parameters have influence on perception and annoyance of odour. The threshold values are having different levels, depending of the type of odour either from new or existing production facilities or from residential or industrial areas.

The inadequate use of odour management in the Nordic countries is illustrated by the fact that no countries have applied for the direct measuring of odour concentration. In that case, the nuisance standard setting in Finland and Denmark is developed by national authorities by atmospheric modelling calculation of odour dispersion and to a certain extent assessment of compliance from surrounding residential areas. Respectably, the national threshold values are developed with a local setting, e.g. use of national dispersion models, local wind situation together with individual odour perception and tolerance level. Due to these circumstances, the Nordic regulation and threshold values are difficult to compare. The following section will describe the current practices in the various countries and describe methodology in the regulation of odour and allergens as well as describe which uncertainties the assessment has incorporated.

Regulation in Denmark

In Denmark the compliance with odour guidelines and thresholds is evaluated for the number of animal units and livestock holds between 15 and 250 animal units and assessed in accordance with The Danish environmental authority's declaration regarding livestock manure, *Husdyrgødningsbekendtgørelsen*, from 2002.

Livestock holds with more than 250 animal units often named concentrated animal feeding operation (CAFO) are regulated according to the environmental protection act chapter 5. The Danish environmental authority's declaration regarding livestock manure, *Husdyrgødningsbekendtgørelsen*, from 2002, demands that there must be at least 300 meters between animal stables and settlements with 8 houses or more.

The legal requirements for larger animal livestock are that no significant distinguished odour annoyance must be present. The declaration regarding livestock manure, which is operated according to specific requirements, defines distance between livestock houses and local residential areas. In practice, the odour annoyance is assessed by the local municipality's guidance. The guidance are based on prior German distance regulations and does not include modelling calculations.

The Danish EPA has outlined an odour assessment method for livestock holds larger than 250 animal units. The CAFO's often use odour dispersion models in order to assess the potential odour annoyance.

Danish example on odour assessment and approval

The odour guidance is based on emission inventories and theoretical assessment methods which are used for preparing theoretical assessment of annoyance levels and the distance which are necessary between livestock holds and residential areas in order to prevent odour nuisance. The odour calculations need to be validated, since local conditions can affect the assessment e.g. variation in meteorological condition or odour dispersion from other sources which can influence specific odour annoyance assessments.

The method for assessing the odour annoyance is based on:

- Standard specification for odour emission outlining the table describing the annual variation of odour, the ventilation efficiency in the production units and the size of the specific animal. The number of the animals has a significant influence on the odour emission as well as the size of the the animal.
- Calculation of the recommended distance of annoyance by using the OML model which assesses dispersion. The dispersion calculation is using general dispersion curves.
- Assessing the location of the point source in relation to the common wind direction and the existing household production in the vicinity.

In specific cases a number of tools are used to improve the assessment. The following section is describing the used tools:

- Preparation of dispersion calculation

The used dispersion curves do not allow for differentiating between the size of the animals. All poultry are characterized as chicken, and horses, sheep, cows and goats are all characterised as cattle. In mixed animal holds a general annoyance distance as a mean average is used. If slaughter pigs have a odour emission of 20,000 OU e/s and a sow-hold has an odour emission of 10,000 OU e/s, the annoyance distance must be calculated from a total emission of 30,000 OU e/s. If the whole emission came from slaughter pigs, the annoyance distance was 350 meter, and it was 275 meters if the emission came from sows. The total annoyance distance can then be calculated as $(20,000 \cdot 350 + 10,000 \cdot 275) / 30,000 = 325$ meter:

- Clarification of application which are not causing increased odour annoyance

If an existing production unit is located more than 50% from the nuisance distance, it will be possible to expand the facilities, but only if the enlargement will not lead to an increased odour annoyance to the surrounding communities. If the distance is less than 50% of the nuisance distance, an enlargement will often be disapproved by the authorities. Such a model will be appropriate in areas with small and moderate odour problems, and will indicate if existing livestock holds can initiate adjustment in production without increasing the odour nuisance. The surrounding communities will in that respect experience a deterioration of life quality.

The odour guideline nuisance distance is measured from the point source centre, which means from the livestock stable and to the nearest neighbour house or residential areas where the nuisance criteria is applied. The regulation of the distance criteria is problematic when the point source has several sources, e.g. different stables with different emission and livestock holds. In that case the point sources should be recalculated as an average value and not by a single distance.

Further description of the Danish livestock odour guidelines can be downloaded at the Danish Ministry of Environment.

Regulation in Finland

Finland has experienced an increasing focus on odour annoyance from livestock production during the last 10–12 years. The Finnish authorities conducted a larger integrated odour survey and outlined both nuisance distance guidelines as well investigated dispersion modelling of odour.

The project was lead by the Technical Research Centre of Finland (VTT) with assistance from the Finish Meteorology Institute (FIM). The aim of the study is to comply with the wish for scientifically justified guidelines to assess and reduce odour annoyance. The study includes determination of the odour load from different livestock farming units and investigations in feasible odour reducing technologies. Ultimately the project aims at the elaboration of guidelines for the placement of large production units.

In order to determine the dose response relationship for odour annoyance of pig and poultry, odour measurements were made at two pig farms of different sizes and at two broiler production units. The investigations included olfactometric emission measurements in three seasons, dispersion calculation and population surveys in the surroundings.

The project also focused on identifying simple and robust measure in order to diminish the odour load from agricultural sources. The study showed the contribution of slurry storage out of the total odour load and specified the benefits of covering manure tanks. A decent reduction in the odour load is achievable by simple floating covers. Further odour reduction measures are peat amendment in the manure and the optimisation of the ventilation rate in the sheds.

Guidelines

The study suggested an improvement of the livestock policy in Finland where applied principles have formed certain limited values or set-back distances between livestock production and residential areas. Management obligations for odour emitting plants are set in regional EPA environmental permits.

Traditionally, the most important odour emitting sector in Finland is the pulp and paper industry. The odour impact of reduced sulphur compounds can stretch several kilometres from the factory. Furthermore, waste management, waste water treatment plants, livestock farming and the chemical and solvent using industry have caused odour complaints. The impact of these activities is usually limited to less than 0.5 km, although large waste handling centres and pig farms can cause significant annoyance depending on the plant volume.

Due to environmental measures, the odour load and annoyance have generally diminished, however agricultural odour being an exception. The reason is that the production units in Finnish livestock production are increasing significantly. Large animal houses are built closer to dwelling houses and as a consequence, odour annoyance becomes significant.

Since the end of the 1990's, the environmental authorities have made strong requirements in order to improve the scientific basis of the odour regulations especially in the agricultural sector to increase their acceptance and effectiveness. This problem is addressed in the Finnish BAT

documents for intensive livestock production [Mikkola et al 2002, Puumala & Grönroos 2004] and further elaborated in a couple of larger research projects [Arnold 2006; Olsen *et al* 2005].

Finnish studies have showed the significant contribution from slurry storage to the total odour load and specified the benefits of covering manure tanks. Decent reduction in the odour load is achievable by simple floating covers. Further odour reduction measures are peat amendment in the manure and the optimisation of the ventilation rate in the sheds. Peat also diminishes methane emissions from sludge. Emission modelling showed that no positive effect from concentrating and elevating odour emission points gave a positive effect on the odour situation in the vicinity of the farm. Odour reducing measures had a positive effect on other environmental parameters. A positive relationship between odour, ammonia and methane reduction is often applied.

Further studies include spatial epidemiological studies using questionnaires and GIS. GIS is used to identify the studied population around the sites in question and to explore the results from the questionnaire studies on maps.

Regulation in Norway

Norwegian farms are small by European standards, the average size of organic farms being about 13 hectares and conventional farms around the double. Most of the farms, especially the larger, grain-growing farms, are mainly located in the south-eastern parts of the country. Sheep, cattle and goats are mainly kept in the south-western, western and northern parts.

The production and livestock intensities have increased by 50% since 1995 although they are not as intensified as in South Sweden or Denmark for that reason the authorities have not yet implied policy regulation or control of the livestock production.

There is no comment odour legislation in Norway or nuisance guidelines from livestock production and residential areas.

Eduard, W. and other conducted a comprehensive study based on questionnaires from adult Norwegian farmers investigating if the farming exposure cause or prevent asthma. The result shows that exposure to endotoxins and fungal spores appears to have a protective effect on atopic asthma but may induce non-atopic asthma in farms (Eduard et al., 2004). The findings have not yet been incorporated in a legal context. The authorities have not expanded the research focus on bioaerosols and asthma as suggested in the other publications.

Regulation in Sweden

The Swedish Environmental law has not incorporated specific odour limit values.

Children as a vulnerable group in the agricultural sector have not been targeted by other than the Swedish government. Lundqvist and Alwall have suggested Swedish guidelines for children's agricultural tasks, the suggestions are centred on the potential risk which agricultural tasks incur. The objective of the suggestion is to establish guidelines for children's agricultural tasks to meet the demands for legislation to support farm families with guidelines which may help them handle this situation (Lundqvist and Alwall, 2004). These guidelines could also incorporate guidelines for odour and exposure of bioaerosols and stress that children as a vulnerable group must be considered as more sensitive to odour and to a certain extent bioaerosols.

Swedish farming is mainly run by the farmer and his family. About 90% of the farmers are organized in the Swedish Federation of Farmers (Höglund, 1998). The federation is offered a program of health check-ups every second year, information and advisory activities, and the possibility of consulting the health centre in case of problems. The initiative is unique in respect that it holds occupational health information obtained voluntarily from the last twenty years. The health centre is playing an important role in supplying information to all its members on new health related conclusions as regards the health impact related to odour and exposure to bioaerosols. The Swedish model would be a useful tool to improve the occupational health situation of farmers and their families by suggesting methods to reduce the poor working environment which additionally will reduce the livestock emission to surrounding communities. Experience in this fields shows the need for occupational health surveillance is urgent. There are great possibilities to prevent further health impact and related diseases. To be successful, however, it is important that the farmers and farmers' organizations are taking an active part in the work (Höglund, 1998).

Sven Nimmermark from the Swedish University of Agricultural Sciences has suggested five odour regulation approaches used for reducing odour nuisance from agricultural operations: 1) setback distances specifying only sources (animal type) and receptor (single house, urban area, ect.) 2) setback distance calculated by formulas using site-specific information, for example, the source. 3) Concentration limited for a specific compound in the ambient air, such as hydrogen sulphide. 4) OU (similar to OU/m^3) limits referring to dispersion modelling, and 5) legislation prohibiting annoyance found by field inspectors.

Other European policy objectives

The policy objective in the Dutch Second National Environmental Policy Plan (NEPP2) is that no more than 12% of the Dutch population would suffer from odour nuisance from road traffic and industry in 2000, with agriculture being classified as industry (VROM, 1993). The percentage of

12% is based on the assessment of odour nuisance made by Statistics Netherlands. In addition to the odour nuisance objective for 2000, another objective states that, in 2010, the Dutch population should no longer experience any severe odour nuisance. This objective is based on the severe odour nuisance measured with the TNO method. No new objectives are set out in NEPP4 (VROM, 2001). The objective for 2010 as regards severe nuisance has been maintained.

7.2 Political implication

The following suggestion is supposed to address a political debate regarding the intricate predicament with odour annoyance and dispersion of allergens from livestock farming.

Limitation in current limit values

Most limit values for odour are based on different percentiles of hourly mean concentration, and in many cases the hourly values are subsequently corrected to account for the short-term (e.g. 1–5 minute) peak values occurring within an hour (Oxbøl 2002). The odour threshold of 1 OU m⁻³ is often exceeded by the limit values of 3 OU m⁻³, which means that there is no direct regulation of the odour concentration above the limit values and more importantly, there are no regulation between the odour threshold and the limit values. This might not have any major impact when the same type of point sources are assessed, the case varies when different release heights are compared. The explanation of this dilemma is caused by disparity of meteorological condition. High concentrations at the ground originating from high release heights are occurring during certain stabilities' conditions (e.g. moderate wind, unstable boundary layer), which limit the number of meteorological occasions, but for low released height with building effect the odour will often be present at ground level and as first approximation the concentration depends only on the wind speed. Consequently, the low sources will more frequently contribute to the total odour exposure (Løftstrøm 2004).

Different odours have different intensity in relation to the concentration. In general this means that for odour concentrations less than about 5–10 OU/m³, small changes of around 2 OU/m³ can easily be recognized, whereas at levels above 20 OU/m³ changes must be more than 10 OU/m³ to be recognized. When the level of odour annoyance in the neighbourhood of an odour source is assessed, then the frequency and the duration of odour thus play a major role.

The concentration fluctuation is important for the odour impact. The human response time is only few seconds. In the vicinity of odour sources, the odour concentrations will fluctuate widely around a mean

value, e.g. the hourly mean. The relation between mean and peak values is not constant, but depends on several parameters (Olsen et al 2005)

The human adaptation to odour and the later recovery of the sense of smell is another difficult parameter in odour impact assessment. The time to adapt varies from a few minutes to more than 10 minutes, the recovery may be faster however. Both vary between individual and the type of odour.

The limit values might also reflect the kind of statistics that regulatory dispersion models are capable of calculating. The differences concern the basic averaging period, the period varies from hour, minute or seconds whereas the assessment varies from day, month or year and the level of percentile (99.9 to 85). An often used limit value is the 98-percentile of hourly mean concentration for one year, but the level of the limit value can vary a lot between countries and for the type of odour or the location.

Several countries use limit values based on short-term concentrations, but the control of compliance is based on dispersion modelling of hourly mean values that afterwards are corrected to the short-term values by the application of simple methods.

Every limit values employ the concentration level but the authorities in Germany have started to take hedonic tone into account (Both and Koch, 2004) The authorities in Denmark have been suggested to use short-term odour intensity instead of the concentration as basis for a new guideline.

The introduction of a national standard on odour measurement presents a new challenge for Nordic olfactometry laboratories to meet tough new instrumental performance and panellist performance criteria. It also raises issues for end users of olfactometry results. For examples regulatory authorities may need to review the international status of odour regulations and guidelines.

Research on odour from livestock farming

Research on odour emissions from livestock farming has focused on i.e. defining emission factor data for pig and broiler for future odour impact assessments. Furthermore, research activities have focused on identifying simple and robust measures to diminish the odour load on other surroundings.

Emission factor data for pig and broiler production has been established for odour impact assessments. The emission data for pig production was slightly higher than results obtained in other countries, although in the same order of magnitude. Emission rates are influenced by a range of local factors including feed, manure management, building design and ventilation rate. Certain lack of unanimity in published odour emission data speaks for the importance of using data obtained in representative national conditions. Finnish agricultural circumstances differ noticeably

from those in Central Europe or North America concerning both climate and production methods.

Odour annoyance studies have showed that peoples' reactions to pig and poultry odour are very different. Thus, no clear indication for need for set back distances for mid-size the poultry production plants could be identified in the investigated plants. On the other hand, there seems to be a need for significant set back distances for large swine production units (if no odour reducing measures implemented)

Gaps in the legal framework

- Odour nuisance and ammonia emissions are closely linked. However policy on these two must improve. There are no real abatement measures with respect to excess odour nuisance, while much effort is put in abating high levels of ammonia. There is an urgent need to implement odour annoyance guidelines.
- Implementation of differentiated safety zones between livestock houses and residential areas in order to reduce odour and flies annoyance, risk of allergens and noise. Denmark and Sweden have recommendations on safety distances of 500 m from larger pigs farms, but it is recommended to imply a differentiated safety zone depending on the number and types of animal.
- In the regulation proposal, it is recommended to enforce registration of livestock from leisure and recreational use, a GIS platform describing the number and type of animals is recommended as well. More animal registration will improve agricultural management with respect to annoyance, emergency management and assessment of potential health risk.
- There is an urgent need for reducing the emission of environmentally harmful substances by implementing recognized abatement techniques.

Research gaps

- Better understanding of the dispersion and transport of allergens from livestock houses and ventilation stacks to surrounding residential areas. Little is known about the distances these particles are transported though the air outside the animal buildings.
- There is a great need to evaluate health effects due to exposures that originate from concentrated animal feeding operation emitted into the environment. Little is known about exposure-response relation of endotoxins. (Endotoxins are the cellwall components of gram-negative bacteria and there compounds are released after the death of the bacteria)
- Further research on the relationship between ammonia and odour emission is necessary in order to understand the importance of emitted

ammonia in odour formation and also to potentially use ammonia measurements as an indication of odour levels.

Review of permits

Environmental permits are granted to units that emit or that may emit substances that cause odour nuisance. At present, this procedure is based on the Environmental Management Act and odour regulations which mostly date from the eighties. For example, intensive livestock holdings are granted permits if they are situated at a certain distance from properties that are susceptible to odour nuisance. Here, the procedure looks at farms that are already present (accumulation) and at the function of adjoining properties. For houses in built-up areas, the distance is larger than for homes in the country. This distance is determined on the basis of the size of the herd.

Future policy

The agricultural odour policy is currently under review. The reason for this is the restructuring of agricultural land. If the proposals for a new agricultural odour policy are approved, this will result in a relaxation of the standards for odour nuisance generated by agriculture, because the sources already in place will be taken into account less than previously when permits to farms were granted.

Link to other policies

Although odour nuisance and ammonia emissions are closely linked, policy on these two subjects is not. There are no real abatement measures with respect to excess odour nuisance, while much effort is put in abating high levels of ammonia. The latter is done in the context of abatement of acidification/eutrophication of nature areas. Only recently, the contribution of ammonia in the secondary aerosol formation is also considered as a reason for abating emissions.

Present policy in the Netherlands with respect to ammonia emissions is largely based on the implementation of the National Emissions Ceilings Directive and thus focuses on meeting the emissions' targets for the Netherlands. Different generic measures have been introduced in order to reduce the overall emissions:

- incorporating manure in the soil when spreading
- use of emission low stables
- covering outdoor manure storages

Besides, these generic measures focusing on emission reduction, also other measures came into force in the context of nature conservation. These measures are of a more local nature, while they deal with e.g. spatial planning around protected nature areas (e.g. Natura 2000). High deposition peaks in the neighbourhood of these areas are abated by specific tailor made measures targeting individual farms. Another way of preventing an increase of deposition to these areas is by implementing protection zones around the nature areas. In these zones (250 meter wide) there is an absolute emission standstill for all farms located within these areas. This means that expansion of farms is possible, but an increase of emissions is not allowed. In order to ensure this, farmers have to take measures to prevent increasing emissions (e.g. emission low stables).

8. Other national contributions

Dutch odour description in relation to airborne emission from livestock

Dutch environment policy makes a distinction between odour nuisance and severe odour nuisance. The Second National Environmental Policy Plan (VROM, 1993) contains objectives for these problems.

Distinction between nuisance and severe nuisance

The Dutch government uses two definitions for the environmental problem of odour nuisance: odour nuisance and severe odour nuisance. The concept of odour nuisance is based on the terminology used by Statistics Netherlands in its “Permanent Onderzoek Leefsituatie” (translated as “Ongoing Survey of Living Conditions” or OSLC). The term “severe odour nuisance” comes from the periodical nuisance survey conducted by the Dutch research institute TNO (also known as the “questionnaire survey”).

Odour nuisance (in the Statistics Netherlands definition) is defined as experiencing frequent or occasional nuisance from stench, in line with the questions asked in the OSLC (CBS, 1995). Sources of odour included in the survey are road traffic, industry or business, agriculture and open fires/multi-burners (see figure above).

Severe odour nuisance (in the definition given by TNO) is based on the question from the periodical nuisance survey of TNO about the extent to which people see a specific source in the living environment as a nuisance on a scale from 1 (not a nuisance at all) to 10 (extreme nuisance). People giving answers in the 8 to 10 range are classified as experiencing “severe nuisance”.

It is not easy to compare the concepts because of the different ways the questions are formulated and the different definitions of the sources. As a result, the Statistics Netherlands survey and the TNO questionnaire survey yield different results.

8.1 Extent of odour nuisance

An annual survey conducted by Statistics Netherlands into the appreciation of the human living environment shows that, in 2001, 15% of the population in the Netherlands suffered from a nuisance caused by odours from road traffic and/or industry (CBS, 2002). The same survey also shows that agriculture, open fires and multi-burners are major sources of odour nuisance (see Table 1).

Table 1: Odour nuisance

	1990	1995	1998	1999	2000	2001
Traffic and/or industry	23%	18%	15%	15%	15%	15%
Agriculture	16%	12%	11%	11%	10%	10%
Open fires and/or multi-burners	11%	10%	9%	9%	9%	8%
Other	50%	60%	65%	65%	66%	67%

Source: CBS (2003).

N.B. Odour nuisance in people aged 18 and older. Odour nuisance (in the Statistics Netherlands definition) is defined as experiencing frequent or occasional nuisance from stench, in line with the questions asked in the Permanent Onderzoek Leefsituatie (1995). Sources of odour included in the survey are road traffic, industry or business, agriculture and open fires/multi-burners

TNO research shows that sewers are the main source of odour nuisance: 19% nuisance and 11% severe nuisance. The Statistics Netherlands' survey does not ask about odour nuisance from sewers.

9. Discussions

The concentration of animal feeding operations has been criticized for posing environmental and human health risks. The intensifying production of animals is among others leading to odour annoyance, nuisance and dispersion of allergens. The social construction of the idealised countryside has accelerated the migration from the urban sphere to the countryside. Further, the economical development in the Nordic countries has accelerated this migration trend and as explained previously has created tensions between the growing livestock operation and the rural residential areas. The anxiety relates to the potential health effect, long-term degradation of the environment and economic impacts on the properties. Thus, the occupational working environment of the farmers is the largest health risk due to emission from livestock.

The complexity of limiting emissions from livestock farming and in this respect reducing odour and dispersion of allergens depend on many variables. The emission is dependent on the design of the stables, the ventilation systems and the handling of manure. The management of the farming operation does also play an important role regarding manure handling, bedding in the stables, livestock feeding and control of humidity and temperature in livestock building.

In order to improve odour annoyance and neighbouring areas' exposure to bioaerosols, it is recommended that a straight 300 meter buffer zone to the nearest residential areas is enforced by local authorities when existing livestock operations are expanding.

The current scientific knowledge of the exposure to bioaerosol and the odour annoyance from livestock production units still need further research before it is possible to conclude that the health is affected by the surrounding residential areas. Thus, the scientific literature indicates that the information is not sufficiently detailed or complete to understand the extent of health impact.

Suggested further research

The report indicates a need for future studies in the area. There is a limited knowledge in a number of relevant and important research topics regarding the impact of odour and dispersion of allergens from livestock productions units.

Some suggestions for important future research are listed below:

Few studies are focusing on the relation between respiratory symptoms and lung function in farming populations, and few studies have investigated the interrelation between exposure measurements inside the animal houses and the occupational health of workers inside the building. Hence, it is difficult to establish a dose-response relationship. Studies among school children have shown a significant inverse association between indoor endotoxin levels and the occurrence of hay fever, atopic asthma and sensitisation. However, other bioaerosol components such as fungal spores, bacteria, storage mites and other allergens have not been widely studied and may also be important.

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