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Application of Odour Predictions to Spatial Planning, the Case of Agricultural Biogas

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The agricultural biogas *i.e.* a renewable energy source, which uses waste from food industries as an input material is discussed here to demonstrate the possibility of incorporating odour impact issues into spatial planning procedures in Poland. Since there is no reliable methodology available domestically, the possibility of adapting procedures and tools applied in Germany has been examined. The availability of data, the development of scenario assumptions for the modelling of protection zones, as well as the initial indication of a final methodology, which could be employed to integrate the odour impact issues into the spatial planning and investment procedures are presented herein. The aim of this study is to establish procedures for the development of biogas plants using food industry waste in Poland, by combining the odour imission prognoses with spatial planning procedures. The German methodology and software (an open source Austal2000G) is used to model the protection zones around such projects, supported with local meteorological and topographical data.

1. Introduction

This research focuses on the boundary protection zones around agricultural biogas plants, with a special consideration to odours. The idea of incorporating protection zones into spatial planning procedures originates from the agricultural sector (animal breeding) and the municipal waste and wastewater treatment. Such an approach was used already back in the 1960-ties, *i.a.* in: Austria, Belgium, Canada, Germany, Holland, Poland, Sweden and Switzerland, (Kulig, 1991; Piringer and Schauberger, 1999; (Schauberger *et al*., 2001; Nicolas *et al*., 2008; Vieira de Melo *et al*., 2012).

According to (Basta, 2012) protection zones should be delineated using both the technical and social criteria. In the Netherlands a concept, dating back to the 17th century (Velden and Kreuwel, 1990), stresses the role of pollution prevention by dividing the land use into 3 categories: 1) attention zones, which require a detailed analysis preceding any building activities, 2) jurisdictional zones, which permit or limit additional housing development, and 3) physical zones, which contain no sensitive land use functions. The sensitive land use functions include a) areas of high sensitivity (residential buildings, hospitals, sanatoria, retirement/nursing centres, recreational facilities, and tourist accommodation); b) areas of medium sensitivity (business facilities, houses in rural areas, scattered dwellings, recreational daytrips, offices, shops; and c) areas of low sensitivity (business and industrial parks) (Province of South of Holland, 2010).

Investment projects utilizing food industry waste trigger local community resistance and location problems. Although the agricultural biogas technology is considered the most environmentally friendly form of waste utilization and production of green renewable energy, it is subject to NIMBY effects. In Poland the odour nuisance has been indicated as the main obstacle preventing this technology from gaining general public acceptance. It is particularly difficult to balance the environmental and social advantages, and arrive at a location compromise in the environment where there are no legal guidelines on how to include odour impacts into investment procedures. Public authorities and investors face social protests, the rationale of which is very difficult to appraise without reliable tools. NIMBY effects have been typical to mature markets, where appropriate response procedures have already been established. In Poland both the market and the procedures are immature and prevent a technological take-off of this technology .

According to the Polish ‘Spatial Planning and Development Act’ all renewables with the power output in excess of 100 kW should be designated together with their protection zones. There is no clear indication of the procedures stipulating the size of the protection zones, however a simplified legal procedure was introduced in Poland as early as in 1967. That regulation specified 5 protection zones categories, namely

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class I 1,000 m, class II 500 m, class III 300 m, class IV 100 m, and class V 50 m. The amended version of the regulation (adopted in 1982 and repealed in 2000) established the procedure of delineating the protection zones either by calculation-measurements or using predefined zone widths. There was no mentioning of biogas plants at that time, nevertheless, the regulation specified not only numerous wastewater treatment plant projects (WWTPs), but also landfill sites and food industry locations, for which comparable odour nuisance can be assumed. It's important to remember that the list of municipal/industrial sites shown in the table below is out of date (the 1960-ties) and the relevant protection zones can be used only as background information.

Table 1: Width of the protection zones specified in the Polish legislation repealed in 2000

Activity	Size	Protection zone width
Mechanical WWTPs	> 5,000 m^3 d^{-1}	1,000 m
	200 - 5,000 m^3 d^{-1}	500 m
	< 200 m^3 d^{-1}	300 m
Mechanical-biological WWTPs	> 5,000 m^3 d^{-1}	500 m
	200 - 5,000 m^3 d^{-1}	300 m
	< 200 m^3 d^{-1}	100 m
Landfill sites, composting plants*, thermal biological treatment plants, municipal waste utilisation plants*	any	500 m
Organic waste storage facilities	< 10 ha	500 m
	>10 ha	1,000 m
Silage drying and beer production facilities	not specified	100 m
Large bakeries and confectionery plants	20,000 t d^{-1}	
Milk, oil and flour production	not specified	
Vegetable, fruit and coffee processing	not specified	
Abattoirs, meat processing plants	< 3,000 small animals d^{-1} < 5,000 / 8,000* t y^{-1}	300 m
	> 3,000 small animals d^{-1} > 5,000 / 8,000* t y^{-1}	500 m
Bakeries, abattoirs, meat processing plants	small	50 m

Source: Polish Regulation of the 9th of November 1982 (...),*Regulation of the 30th of May 1967 (...)

The aforementioned protection zones were to be used as an input for spatial planning procedures. In Poland the 'Spatial Planning (...) Act' obliges municipalities to prepare two types of documents: 'Study on Commune Land Use Conditions and Directions' (Polish abbreviation: SUiKZP) and 'Local Zoning Plan' (Polish abbreviation: MPZP). The former is produced for the whole municipality area and determines its spatial policy. The latter is a local regulation produced for a specified area within the municipality. The application of the spatial policy defined in SUiKZP to investment procedures is not mandatory if MPZP is not in place (which is often the case in rural areas). The question relevant for this research study is how the odour impact issues can be incorporated into the aforementioned spatial planning procedures.

2. Materials and methods

2.1 Choice of reference procedures

In some countries regulatory solutions for odours provide for the occurrence frequency calculation, *i.e.* how often a given odour concentration level is exceeded, whereas in other cases minimum separation distances are required (Capelli *et al*., 2013). Germany has over 20 years of experience in the odour impact predictions based on dispersion modelling, and the said predictions are used both in spatial planning and investment procedures under the 'Federal Immission Control Act' and the 'TA Luft'. Additionally, the GIRL Guideline, although not legally binding, specifies detailed methodological instructions. A severe nuisance takes place if the total odour exposure exceeds 10% of hours per year for residential and mixed areas, 15% for villages and commercial and industrial areas (Lang, 2008). In the dispersion modelling the odour hours are derived from the hourly mean values multiplied by the factor of 4, *i.e.* if within an hour of measurement the value of 0.25 ou_E m^{-3} is exceeded then this hour is considered an odour hour (Schauberger *et al*., 2012b). Schauberger *et al*. (2012c) argue that although factors between 1 and 10 are applied in other countries, the German peak-to-mean value of 4 has been well calibrated by empirical field measurements. However, they also stress the fact that low values may underestimate odour sensation the closer to the emission source.

The odour impact predictions are required as an input both for spatial planning and permit issue procedures in case of the following projects: furnace thermal capacity over 1 MW (equivalent to *c.* 300 kW_e), fermentation input material in excess of 10 t d^{-1}, and an animal waste container in excess of 6,500 m^3 (TA Luft). The protection zone's widths are predefined at 300 m for sealed containers and at 500 m for non-airtight solutions. They can be decreased if odour imission predictions are made.
The reference procedures applied in Germany cannot be simply transposed to Poland without any modification. In Poland the first biogas projects have been much bigger (average plant size is over 1 MW_e in Poland compared to 300 kW_e in Germany). Moreover, as a result of support schemes, German plants use energy crops more often, whereas in Poland cheaper solutions, based on free food processing industry waste with high energy content are more common. All that results in different approaches to odour impact.

2.2 Choice of a model

Nowadays, the distance (from an odour source) required by law is calculated based on the dispersion modelling rather than the olfactometry (Capelli *et al*., 2013). Therefore, the protection zone width for agricultural biogas plants will be modelled and odour dispersion tools will be reviewed. Gaussian models are simpler, whereas Langrange-particle models demonstrate the dynamics of both the topographic and atmospheric conditions. The advanced models include: computational fluid dynamics model (CFD), Navier-Stokes model based on 3-dimensional equation, and advection/diffusion (Euler) model. German Austall2000G model made available to general public by German Federal Environmental Agency has been chosen as a possible tool for application in Polish conditions.

Table 2: Tools for modelling of odour dispersion

Classes	Models	Advantages/disadvantages
Gauss plume models	ISC3 ⇒PRIME ⇒ AERMOD, INPUFF-2 ⇒ OFFSET, AODM,CERC/MetADMS, CALMET/CALPUFF, CSIRO TAPM, COMPLEX1, LTDF, NAME, MM5, OML, ONGAUSSplus, ADMS,WRF	(+) low cost and simple in use, input data availability (-) does not reflect temporal and spatial changes of meteorological conditions easily (-) not applicable to multi-emission sources
Langrange-particle models	**AUSTAL2000G,** CALMET/CALPUFF, LAPMOD, LASAT, NaSt3D	(+) high precision of calculations (-) high demand for input data (-) appropriate only for flat terrain, up to 20% inclination
Advanced models	CFD, NaSt3D, IBJodour (MEPOD)	(+) high precision, advanced meteorological models (-) high amount of complex input data

Source: (Capelli *et al*., 2013; Vieira de Melo *et al*., 2012; Schauberger *et al*., 2012b; Environment Agency, 2007; Boeker *et al*., 2000).

2.3 Emission data

The German TA Luft indicates that data can be derived either from olfactometric measurements or from reliable literature sources. Over the years quite an extensive data base on emissions from agricultural or municipal infrastructure (WWTP, landfills or waste recycling sites) has been developed (Lee *et al*., 2013; (Kulig *et al*., 2010; Sarkar *et al*., 2003).However, data about food processing industry emissions should be handled with due caution, because specialised publications do not provide data about many substrates and the emission range sometimes is very broad (Vieira de Melo *et al*., 2012), (Schauberger *et al*., 2012a); *e.g.* for fruit/vegetable waste it is between 2,000 to 15,000 ou_E m^{-3} (Holger and Steiner, 2013). Examination of the odour prediction studies for German biogas plants made it possible to identify crucial emission sources. Some specific area emission factors include maize silage: 3 to 15; grass silage: 8; vegetable waste: 5; fruit waste: 30; pig slurry: 7 to 10; chicken manure: 50; green waste: 50 ou_E m^{-2} s^{-1}. Specific flux emission rates for the CHP are 3,000 ou_E m^{-3} for the Gas-Otto and 5,000 ou_E m^{-3} for the spark ignition engine (Holger and Steiner, 2013). Additionally, different technical operations influence the expected emission rates*, e.g.* the results should be multiplied by 1/3 if a storage facility is covered by a non-gastight membrane, or by 3 if the upper skim of a fluid storage container is disturbed.

2.4 Meteorological data

Data should be recorded over 1 year with a 1 hour concentration or higher (*e.g.* 15 minutes) (Capelli *et al*., 2013), and a representative year should be analysed. Unlike Poland, where Pasquill dispersion categories prevail, in Germany Klug/Manier are common. The instruction to Austal2000 recommends a simplified approach where stability classes are assigned: extremely stable (I, F), stable (II, E), neutral to stable

(III1, D), neutral to unstable (III2, C), unstable (IV, B), extremely unstable (V, A) (Janicke Consulting, 2011). Beside wind velocity and direction, also stability classes are a prerequisite of odour dispersion modelling for their calculation data on clouds cover and insolation is required (VDI 3782, 2009).

2.5 Terrain data

In the German TA Luft the roughness length of the area z_0 is mentioned for each of the Corine Land Cover (CLC) register, whereas in Poland some of the classes have been additionally differentiated depending on the season of the year, *e.g.* for inland waters, pastures and arable land. In the Polish literature the measurements of roughness length use the spatial planning terminology rather than that of CLC register (Kulig, 2004).

3. Results and discussion

3.1 Delimitation of the study area

In order to designate the most interesting study area, which later can be used as a basis for development of a protection zone delimitation procedure, a simplified multi-criteria method has been proposed. So far, the data to be used for the analysis has been collected only from six locations, most suitable for the analysis. The most suitable one is Głuchów, located in the fruit production area. There are around 31 food industry facilities in the vicinity of that plant. The urban sprawl effect of Warsaw metropolitan area is strong, thus, the predicted social acceptability for a new industrial project is low. The investor proposed the following substrate input: apple pomace 39,500 t y^{-1}, grass silage 3,500 t y^{-1}, cow slurry 10,950 t y^{-1}, frying oil 700 m^3 y^{-1}. The first substrate delivery was considered unrealistic, therefore, it was decreased to 15,000 t y^{-1} and additionally 15,000 t y^{-1} of maize silage was added in order to support the assumed energy production. Initial results of emission rates for Głuchów case study area are presented below (Figure 1).

Table 4: Simplified multi-criteria method for the choice of the case study location suitable for the analysis

Location	Domosław	Głuchów	Klepaczew	Kosów Lacki	Witkowizna
Substrates					
Amount	63,000 t y^{-1}	55,000 t y^{-1}	c. 10,000 t y^{-1}	33,000 t y^{-1}	4,700 t y^{-1}
% of food processing industry waste	40%	73%	0%	18%	>10%
Maize silage within 20 km	Low	Good	Very low	Low	Medium
Capacity	1.6 MW_e	2.4 MW_e	2 MW_e	1.6 MW_e	0.6 MW_e
Spatial planning issues					
Prevailing function	Agricultural	Urbanization process	Recreational and touristic	Agricultural	Agricultural
Proximity to living areas	> 600 m	> 300 m	> 600 m	> 300 m	> 600 m
Population density	Low	High	Low	Low	High
Environmental issues					
Substrate logistic nuisance	Low	High	Very high	Medium	Low
Environmental added value	3 nearby industrial sites	Brownfield site	None	None	None
Social acceptability	Neutral	Low	Very low	Neutral	Neutral

3.2 Scenario development

Development of a scenario is a part of the analytical network processes, the purpose is to transform the input data (with their technical and spatial component) into output decisions, *i.e.* answers about where, when, what, and how much (Ferretti and Pomarico, 2012), and in this particular case: "*what is the recommended size of the protection zone around the analysed investment projects to be included into the spatial management plan*". The factors used in making of imission predictions can be divided into controllable ones (choice of substrates, air tightness, greenbelt fencing) and those which cannot be controlled (wind velocity, human error, device failure) (Gabriel *et al.*, 2010).

Technological scenarios can be considered as alternatives required within the scope of the Environmental Impact Assessment under the Polish law.

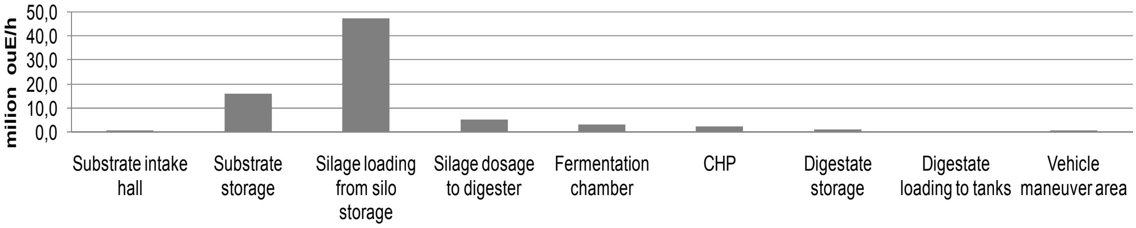

Figure 1: Emission rates from the Głuchów agricultural biogas plant

The technological alternatives refer to the technological chain units, which are most sensitive to the increase of odour impact: 1) the change of substrates to those having a bigger odour impact; 2) employment of a less airtight technology; 3) technology change, *e.g.* from wet to dry fermentation. Apart from the aforementioned alternatives, the impact of unusual events (breakdowns or unsealing of airtight containers), which can result in sudden and unexpected cases of odour emissions, as well as maximum emission values should be analysed.

4. Conclusions

The analysis performed so far is a part of a bigger project, which, when completed, should contain recommendations for the incorporation of odour issues into spatial planning procedures. The initial research made it possible to conclude that the incorporation of odour nuisance issues will be possible only if, in majority of cases, a simplified method for the delineation of protection zones is proposed. A preliminary assumption for such a screening procedure is that threshold criteria shall apply to projects under 500 kW_e with the share of substrates from food industries below 20 %, where the topographic conditions are typical, the population density is rather low, and, finally, no sensitive land-use function is planned. The modelling as a more advanced, difficult and costly procedure should be applied only in case of projects, which will not be able to pass the screening procedure. The protection zones should be calculated with the help of other models, as well. It would be interesting to see how the zones differ if a simplified diffusion model, *e.g.* Polish KOMIN, is applied, or to see results produced by a comparable Langrange model, *e.g.* Calpuff. The following question needs answering: what is the targeted scale of the analysis to mitigate the social protests. The scale of the Austal2000G can be compared with the scale of a zoning plan (MPZP), *i.e.* 1:1,000. However, in the case of big projects in excess of 1.5 MW_e using more than 50 % of food industry waste, the feared impact is much larger. Inhabitants are usually interested in odour impact predictions of a wider range (up to 5 km). Other odour dispersion models cover a wider geographical range (Yu *et al*., 2009). Further research requires development of a careful *ceteris paribus* sensitivity analysis in order to show how widths of recommended protection zones change.

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