PM emissions and mitigation options from agricultural processes in Germany

O. Beletskaya[1], I. Huck[2], E. Angenendt[1], J. Theloke[2], J. Zeddies[1], and R. Friedrich[2]

Abstract

Agriculture is one of the sources of particulate matter (PM) emissions to the atmosphere. For calculating emissions and assessing abatement potentials of mitigation measures, an economic-ecological modeling system is elaborated. The main target of the model is the improvement of the German agricultural inventory. Primary PM with fractions of 10 and 2.5 µm is taken into account, because of a high concern for the environmental policy due to relevant health impacts caused.

Abatement strategies for the particulate matter emission will be formulated and assessed in the framework of the regional model, **EFEM** (**E**conomic **F**arm **E**mission **M**odel). Five regions in Germany will be considered: Brandenburg, Niedersachsen, Bayern, Nordrhein-Westfalen and Baden-Württemberg.

In order to get results on the PM emission for these regions, activities (animal husbandry, crop production, fodder preparation, manure management, tillage, land preparation and harvesting operations) of different farm of various types and information on the emission intensities will be compiled with the help of linear programming. Emission factors will be either determined or taken from studies about European agricultural particulate emission and adopted for the **EFEM**. The emission outputs of the model will be implemented into the IER emission model, which is able to calculate high spatially resolved emission data.

The effects of mitigation options to the PM emission from agricultural activities in Germany will be assessed on the base of comparison of the reference year 2003 and scenario 2013.

Finally, implementation strategies of the most efficient mitigation options will be elaborated, regarding technical and non-technical measures in particular under consideration of the economic impacts to the recipients and other regional effects.

Keywords: particulate matter emission, economic-ecological modeling system, abatement strategies

1 Introduction

The contribution of agriculture to the total particulate matter (PM) emission in 2004 - 2005 in Germany was about 9 per cent of the PM10 and nearly 7 per cent of PM2.5 primary emission (Umweltbundesamt). PM with particle sizes of 10 and 2.5 µm is of the highest interest for both political and healthcare organizations. On one hand, information on the emission of the above-mentioned PM fractions is more desirable, because already existing data about it are not enough to fulfill the international reporting obligations, to monitor progress in air pollution and to identify possible mitigation strategies. On the other hand, many studies highlight, that particles of 10 and 2.5 µm, associated with inhalable dust (in some researches – with inhalable and respirable dust respectively), cause serious health problems. In this relation data on PM10/PM2.5-emissions are quite essential for further development of technologies (e.g. BAT - **B**est **A**vailable **T**echnologies) effectively abating PM emission from agricultural systems, as well as of political measures directing agricultural management to a more sustainable way.

2 Objectives

The main objective of the project “Modeling of sectoral, spatial disaggregated balances of greenhouse gases and assessment of environmental protection strategies at the regional policy level” financed by **German Research Association (DFG)**, is to develop an improved German agricultural inventory for ammonia and greenhouse gases emissions. PM-emission, with respect to its assessment, development of possible abatement measures and determination of their effects on other environmental indicators, has become a key issue of this study.

As the result of the research following sub-targets are to be attained:

- Representation of emission “hot-spots” in regions and consequent choice of experiment regions.
- Modeling of the primary PM emission on the level of selected regions and their administrative districts under the consideration of various local conditions and farm structures.

[1] University of Hohenheim, Institute for Farm Management, Germany

[2] Universität Stuttgart, Institute of Energy Economics and the Rational Use of Energy, Germany

- Spatial and temporal distribution of PM emissions in experiment regions
- Appraisal of future emission development and evaluation of abatement possibilities (their potentials, costs, other disadvantages and advantages) and therefore their ordering according to efficiency and political feasibility.
- Transfer of the results for chosen regions on the perspective of the whole of Germany.

In order to reach these objectives an economic-ecological modeling system will be elaborated, also extended, improved, and finally implemented.

3 Research regions

Five regions are taken into consideration: Niedersachsen, Brandenburg, Bayern, Baden-Württemberg and Nordrhein-Westfalen. Each county is subdivided into administrative districts (Regierungsbezirke).

The above-mentioned regions have been chosen for the study, because "hot spots" of emission can be pointed out according to the emission registry, and the choice of the mentioned German counties was made with regard to these "hot spots". To demonstrate the importance of various agricultural emission sources for primary PM, it does make sense to choose regions with different key production activities. Thus, Niedersachsen and Nordrhein-Westfalen are considered because of their intensive livestock production. According to the report of the German Environmental Organization, the highest amount of PM is emitted from livestock farming; in 1995 the emission from animal husbandry in Europe amounted to 4.5 per cent of PM10 and 1.7 per cent of PM2.5 (Umweltbundesamt). Other most important emission sources are fodder, dry manure (uppermost in the poultry houses) and litter. Bayern and Baden-Württemberg were chosen, because of high shares of forage-growing activities presented there (50 and 36 per cent of forage-growing farms accordingly). Besides animal production, PM emissions are registered as well from other kind of agricultural activities, for instance, from arable farming. In this relation Brandenburg was regarded as the region of extensive arable crop production with a high share of arable farms (34 per cent), carrying out their agricultural activities on 38 per cent of the total used agricultural land. It is also important to mention that in all selected regions from 40 to 55 per cent of land is under agricultural use. So, the elaboration of PM-emission mitigation policy looks quite essential for these German counties, concerning the information presented above (Destatis).

4 Methods and materials

4.1 Economic Farm Emission Model (EFEM)

Measurement of PM-emissions at the farm scale is feasible and models allow the most coherent estimating of emissions at the regional scale. However, in many models measuring of PM-emission is associated with great technical requirements and high costs. Recently, PM-emissions caused by agricultural activities are considered in multi-sectoral models (e.g. **RAINS** - **R**egional **A**ir Pollution **In**formation and **S**imulation). Anyway, by the reason of their complexity, detailed examination of the agricultural sector is hardly possible. That is why an ecologic-economical **E**conomic **F**arm **E**mission **M**odel (**EFEM**) was developed (Schäfer M. 2006).

EFEM was used for various projects and, therefore, its key research issue has been continuously extended. Thus, the current work is dedicated to analyze PM-emission from various agricultural systems.

In the model, the target of the economic analysis carried out on the farm-level corresponds to the farmer's interests. Therefore the objective of **EFEM** is the maximization of an individual farm's gross-margin. These farms are regarded as representative for all farms of the same type in the same region, and their objective function can be written as follows:

$$\max_{\boldsymbol{x}_k} \boldsymbol{\pi}_k = (\boldsymbol{p}_i - \boldsymbol{c}_i) * \boldsymbol{x}_k,$$
$$\text{s.t. } \boldsymbol{A}_k * \boldsymbol{x}_k \le \boldsymbol{z}_k, \boldsymbol{x}_k \ge 0,$$

where $\boldsymbol{\pi}_k$ is the total gross-margin of the k-th farm-type, $\boldsymbol{p}_i$ and $\boldsymbol{c}_i$ are n-vectors for the i-th selling price and variable costs of the i-th production activity consequently, $\boldsymbol{x}_k$ is the n-vector of command variables. The constraints faced by farm-type k are defined through $\boldsymbol{A}_k$ and $\boldsymbol{z}_k$, determining $m \times n$-input-output matrix and m-vector of capacities accordingly.

Command variables in **EFEM** are area associated to each crop (including grassland and set-aside area), the number of animals from different categories, and quantity of purchased animal feeding, variables related to policy programs (enrolment in environmental or set-aside programs), total greenhouse gases emissions. In the letter case $\boldsymbol{p}_i$ and $\boldsymbol{c}_i$ are substituted by the tax on emissions (De Cara S. et al. 2006).

EFEM is a mixed integer model, one of special cases of linear programming, where the corresponding variables can be included as both binary and integer. The given approach reflects the possibility of farmers to deal in mutually exclusive policy programs including different obligations and payments. **EFEM** takes into account crop and grassland products and crop by-products, which can be used on farm for feeding purposes, for litter, or green manure selling (De Cara S. et al. 2006).

There are the following constraints defined by $\boldsymbol{A_k}$:

1) Cropping area
2) Crop rotation
3) Animal housing places and animal demography
4) Livestock feed requirements
5) Quotas
6) Restrictions imposed by policy and environmental programs

In **EFEM** total land is fixed at initial land endowment of each farm-type. Crop rotation constraints relate to maximum area shares of certain crops in a rotation process. Based on historical observations and calibrated to reflect common practices and rationality of agricultural business, these constraints aim at substituting the dynamics of crop rotation and thereafter translating it into a static model. Livestock numbers are also limited by the availability of fixed capital (number of housing places). As for modeling of animal feed requirements, the minimum requirements of energy and protein for each livestock category are to be met, as well as for digestible matter. Among quotas sugar beet and milk quotas are distinguished as constraints. Set-aside requirements fell into the category of restrictions imposed by policy end environmental programs (De Cara S. et al. 2006).

The core of **EFEM**, showing an interaction of both economic and environmental elements, is the production module. The model is adapted to find simultaneous solutions of multidimensional problems and adjusted for various farm-structures. Last-mentioned were chosen according to the business alignment (**BWA** – **B**etriebs**w**irtschaftliche **A**usrichtung), with the only exception: horticultural business was excluded from the modeling. Agricultural activities of the following 5 farm-types will be regarded: arable farming, permanent cropping, forage-growing, intensive livestock, and mixed farms.

The model is composed of different sub-models, making possible a representation of all relevant production processes of arable farming and grassland management, with related mechanization, animal husbandry with a disaggregated feeding module, manure management and nitrogen circulation. Besides these mentioned constituents, production modules of each mentioned sub-module also contain energy, emission and stock flow parameters for quantification of emissions caused by the above-mentioned operations. Moreover, greenhouse gases and PM emissions are differentiated according to the production branch, which these gases and PM outflow from (see figure 1).

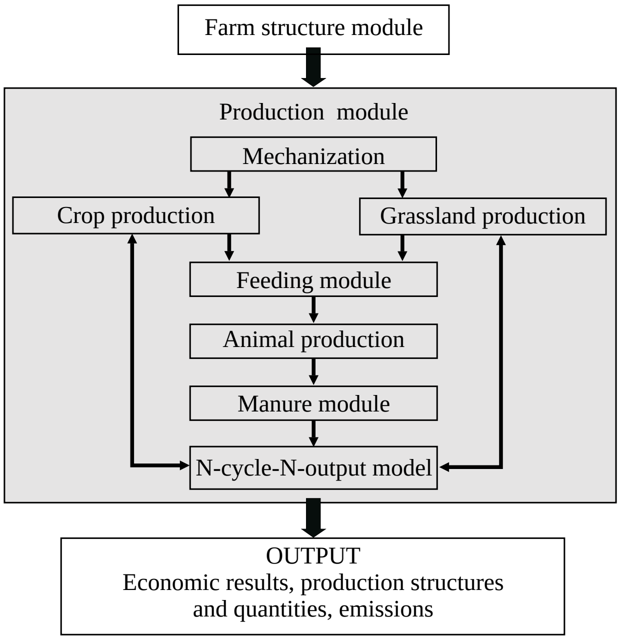

Figure 1:
Build-up of the EFEM (Triebe S. 2007)

Costs and activities data such as yield, productivities, and intensities are different from region to region. All production activities presented in **EFEM** are highly disaggregated according to the level of input-use and performance. Firstly, in general 14 different arable crops are integrated into **EFEM**: winter- and summer-wheat, winter- and summer-barley, oats, rye, winter-rape, sugar beets, potatoes, field beans, sunflowers, grain maize and silage corn, as well as clover-grass. Each crop-production activity can be combined with different fertilization intensities. Secondly, **EFEM** distinguishes between two grassland activities: meadow and pasture (Triebe S. 2007; De Cara S. et al. 2006). Thirdly, livestock production is also subdivided according to levels of performance for main animal categories kept in selected regions. The part of the model devoted to animal husbandry includes data on dairy farming, calves, heifers, bulls, fattening pigs, cows, sheep, and intensive livestock farming with emphasis on hog and poultry production (Triebe S. 2007).

PM-emissions are differentiated in **EFEM** for following agricultural activities: land preparation, seeding, harvesting, livestock as well as forage production and manure management. Therefore, emission factors for these production activities and the operations they comprise are considered in the model. For instance, emission intensities for such operations of arable farming as land preparation, crop production, and harvesting are accounted for. In the case of feeding and manure managements the production of feed and manure consequently is considered. For animal hus-

bandry various types of manure and housing systems are taken into account while determining emission factors.
Information on the emission intensity and farm activities data, integrated into **EFEM** allows analyzing and predicting the development of PM emission firstly on the farm level. With the next step of modeling due to numerous model-calculations, technical and political abatement strategies with the accent on their reduction potentials are examined on the same level. Targeted technical and political options are to be oriented to assess PM emission and, at the result, to find out a proper ways to minimize or even eliminate it.

In **EFEM** optimized results for individual farms will be extended to the regional level due to a special extrapolation procedure.

areas selected for the research will be calculated in a spatial resolution of 5 km x 5 km. Results will be parameterised, so that the emissions in other regions of Germany can be assessed. The spatial resolution of the GIS regarding the whole of Germany will be 10 km x 10 km. If more than one county is located in a grid segment, the respective emissions of each county will be weighted by the relative size of its area, resulting in the average emissions of the segment. The resulting shares are stored in two database tables and used by the **ECM** for multiplication with the yearly emission data and temporal profiles.

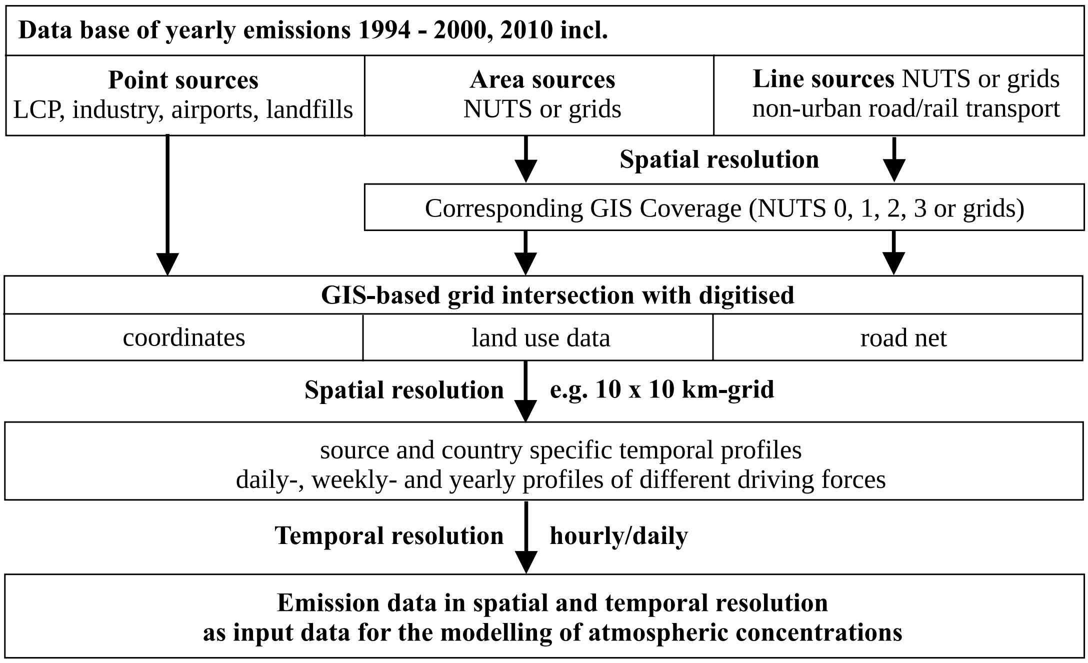

Figure 2:
General approach for the generation of emission data in high spatial and temporal resolution within the **IER** emission model (Pregger T. et al., 2007)

4.2 IER ECM-model

The information on PM-emission resulting from the **EFEM**-model will be implemented into the **IER emission calculation model (ECM).** The latter is developed to calculate emission data with a high spatial resolution. The basic methodology of the **IER** approach is shown in figure 2.

The model starts with a yearly emission table that includes point, area and line sources using different geographic data for spatial allocation of these source types. Spatial allocation based on GIS intersection leads to grid- and cell-shares of emission sources considered. PM emissions in

5 Source data

To build up the regional typical farm-model, bookkeeping data for individual farms in the considered German counties for the reference year 2003 are needed. This information is obtained from **F**arm **A**ccountancy **D**ata **N**etwork (**FADN**). Test-farms are to be assessed on the regional level and, thereafter, averaged. For each region up to 5 typical farms, whose factor endowments are close to average results, will be selected.

FADN databank contains consistent information on costs, prices, areas, and income for all selected regions and administrative districts of Germany. **FADN** provides information on important agricultural products (meat, milk, crops, etc.), but does not take into account any changes of production intensities of a single production process. For each farm type input and production intensities are fixed throughout prices, costs and yields for a certain farm-type. In return that means that the use of **FADN** data requires an analysis of the changes of agricultural management induced by deviations from the original one. This divergence has significant influence on fertilizer application, cultivated crops and so forth (Vabitsch A. M., 2006).

At the result of a comparison between data from **FADN** and regional statistics, significant differences were found. Moreover, figures from **FADN** for the same parameters and regions are lower than those from the regional statistics. Such a difference can be explained by the fact that the bookkeeping information for part-time farms is not taken into account in the **FADN**-database. To be able to project the results from farm to regional level, a methodology for extrapolation was developed. It is based on an optimization approach, which eases the representation of total capacities of regarded regions through the weighting of capacities of typical farm-types. In **FADN** alternative extrapolation factors expressing number of representative farms are used. But for the case of **EFEM** these farms cannot be used as extrapolation coefficients, firstly, because of the deviation from regional statistics. Therefore extrapolation factors are being elaborated according to the approach presented by Schäfer M. (2006). Its basic principle presumes the presentation of a serial of typical model farms, their assessment and weighting in order to match them to the existing regional production and farm structures and, therefore, to represent regional capacities exactly. Rather typical than average farms will be extrapolated in this study. Each of the regional capacities will be weighted with the respective gross-margin to guarantee that they won't be overestimated. Monetary deviations, i.e. sums of absolute under- and overestimations are to be minimized through the optimization approach (Schäfer M. 2006).

Factor endowments for each region will be exactly assessed due to the multiplication of the adjusted farms capacities with the weighting coefficient. Extrapolation procedure additionally assures that farm structures in the selected counties are well represented.

On the basis of bookkeeping data together with information on PM-emission intensities, the presentation of a German detailed agricultural inventory for PM10/PM2.5-emissions from agriculture is to be done. It is the main concern of the work in the described research project. Emission-factors will be provided by **IER** on the base of own calculations and literature research.

The choice of PM emission factors has appeared to be a quite problematic issue, mostly because of the absence of a worldwide unique inventory system. Information on emission intensity for different PM fractions, measurement aggregations and units make it difficult to use emission data for the final modeling without additional preprocessing.

There is still not enough information to conclude about the contribution of, for example, arable farming with relevant operations of land preparation, crop production and harvesting. Even if there is any information on PM-emission intensity, very few studies analyze how uncertain emission factors can be calculated and, therefore, comparison of information on emission from different researchers shows not always clearly where emission data are overestimated and where they are underestimated.

Very often European emission is assumed as being equal or at least equivalent to the American one without consideration of different climate and soil conditions. The uppermost reason is that the emission factors are more readily available in American studies than in European ones. This holds particularly true for emission studies from California. Due to the lack of relevant European research the contribution of some agricultural activities to the total PM emission is still not known as, for instance, in the case of operations on land preparation.

However emission data from some sources are already used in big projects and can be used as well to build up the current model on the PM-emission. Thus, in the **RAINS**-model developed at the **I**nternational **I**nstitute for **A**pplied **S**ystems **A**nalysis **(IIASA)** the existing structure for assessment of gaseous emissions was already extended to estimate PM-emission. For an appraisal of the PM-emission from animal production and arable crop production the most important animal categories and arable farming activities have been chosen, in other words, the aggregation of parameters, regarded as PM-emission sources, in **RAINS** is very general. The elaboration of eventual emission factors in this model is based on the results of two studies: Takai H. et al. (1998) and ICC&SRI (2000).

Some studies from the German Federal Agricultural Research Centre (**FAL**) and the Leibniz-Centre for Agricultural Landscape and Land Use Research (**ZALF**) in turn provide sufficient information on emission from the arable farming. Here the aggregation of PM-emission sources according to different operations is relatively detailed.

The study of Seedorf J. (2004) is another source of information on emission from animal production. Measuring techniques used for this work are different from those applied by Takai H., et al. (1998). This is possibly the most significant reason for differences in the two studies' results. Anyway, emission is measured for inhalable and respirable dust in both works. But if in RAINS inhalable and respirable dust from Takai H., et al. (1998) was associated with PM10 and PM2.5 accordingly, Seedorf J. (2004) suggests transformation factors in order to obtain PM10 and PM2.5 emphasizing that these conversion data should be used very carefully, because there is no clear correlation between inhalable and respirable dust and the above-mentioned PM fractions. Moreover, Seedorf J. (2004) suggested to take into account housing periods to make data more precise and presented the way how these data can be calculated. Klimont Z. and Amann M. (2002) (IIASA) have also suggested to elaborate emission factors considering housing period but the way of its calculation is not clear.

6 Expected results

The most prominent strength, responsible for the results expected from the implementation of the **EFEM**-model, is the possibility to calculate simultaneously both consequences of abatement strategies and development of PM emissions.

The model allows an appraisal of emissions from agricultural systems on farm and regional levels. Calculated results for the PM-emission will be differentiated according to the farm-type and regional conditions. At the result of a sophisticated regional analysis, strategies with the most efficient mitigation options will be chosen, regarding technical and non-technical measures, for the simulation of how agricultural policies (for instance subsidies, law) and socioeconomic framework (prices, labour, etc.) influence farmers' decisions on management options and on intensity of agricultural activities, that eventually affect the expected revenue. Thus, these abatement strategies are to be evaluated through measurements influencing either activities or specific emissions of each activity unit (emission factors), with respect to environmental effectiveness and economic feasibility.

Due to the whole modeling process, depiction of spatial distribution of PM-emission "hot-spots" will be represented through the implementation of GIS. Regional results are to be extrapolated for the whole of Germany. Therefore, the development of an improved German emission inventory is expected from the implementation of the **EFEM**-model. An emission inventory for PM will be presented for the year 2003, effects of mitigation options in Germany will be appraised on the base of the reference scenario for 2013, comparing calculated emission with emissions in a reference scenario. With the scenario 2013, future PM-emission from agriculture will be evaluated under consideration of agricultural policy development.

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