

A MAS model for optimizing the spatial aspects of livestock production and manure abatement

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Abstract

As a consequence of the EU Nitrates Directive many countries have developed policies to regulate manure production and manure emission on land. Farmers have three allocation options: spreading manure on own land, transporting manure to other farmers' land and processing manure. To better understand the manure problem as an allocation problem a spatial mathematical programming multi-agent model has been developed. The model is applied for Flanders (Belgium), a highly concentrated livestock area. Using this model, policy alternatives and their cost efficiency can be evaluated. These simulations result in advice on location and type of manure processing and an indicator which creates transparency in the manure and processing market.

1 Introduction

In recent decades manure became an important issue of livestock production in many Western-European countries. Manure is seen as a 'bad' thing (Lewis 2008) or as an undesirable by-product of livestock production (Huhtala & Marklund 2008). In countries like the Netherlands, Belgium (mainly in Flanders) and parts of France and Italy, where animal production is very concentrated, more manure is produced per unit of farmland than what may be distributed in compliance with legal provisions. In Flanders, which will be used as case in this research, the quantity of nitrogen (N) produced per hectare of land was more than 260 kg in 1991 (Vervaet et al. 2004). Due to policy interventions, N-production has been reduced to 200 kg per hectare of land in 2006. The strong growth in livestock production was possible due to the import of feed compounds from elsewhere in the world. The inexpensive availability of imported feed favoured the growth of the livestock production in regions close to sea-ports (Feinerman & Komen 2005). This dependency of livestock production on sea-ports induced the development of two regions with highly concentrated animal production in Flanders. One is located in the western part of Flanders (the province of West-Flanders), with the adjacent sea-port of Ghent (with further transships to the inland port of Roeselare, which is central to the livestock production area) and the other in the northern part of Flanders (the province of Antwerp), close to the sea-port of Antwerp.

Before 1991, without any policy intervention, the produced nutrients from animal production were mostly disposed of on the farmers' own land. The farmers did not face incentives to bear the extra cost of transporting manure to other regions. They even benefited from the increased crop yield due to the very high fertilisation based on manure (Nesme et al. 2005). Both the excessive manure application and the limited nutrient uptake by crops increased the nutrient concentration in the soil. Because of nitrate and phosphate leaching from the soil, surface- and groundwater were polluted with nutrients (Withers & Haygarth 2007).

In 1991, the European Nitrates Directive (91/676/EEC)¹ introduced the 50 mg nitrate per litre water standard and obliged the regional or national governments to take action against an excessive use of manure and other fertilizers. In many countries, this water quality standard resulted in fertilization standards. Farms with more manure production than the fertilization standards allow for use on their own land, needed to transport manure to farms with deficit on manure. In regions where overall production exceeds deficits, the farmer needs three possibilities to get rid of the produced manure: (1) using the manure on his own land, (2) transporting it to other (deficit) farms or (3) processing or exporting the manure. The first and second option are limited by the fertilization standards and by lack of full acceptance of manure within the capacity determined by the fertilization standards. In Flanders (2006), only 72.5% of produced manure is accepted, whereas the standards would allow 100%. As a result, the quantity of manure which could not be disposed of on land, must be processed or exported. Despite the fact that manure transport is running to its limits, the processing capacity has not yet sufficiently been developed to solve the manure problem. A major problem in this development of the processing capacity is the uncertainty about the manure surplus evolution and related disposal costs.

The regional concentration of animal production is very diverse and, together with high transportation costs, this creates huge spatial differences in the demand for manure processing. The interplay between transportation and processing, determines where demand

¹ The main purpose of the directive was to protect the waters against pollution caused by nitrates from agricultural sources

for processing capacity will arise. Various models have been made in the past to describe this interplay (e.g. De Mol & Van Beeck (1991), Lauwers (1993), Lauwers et al. (1998), ...). However, these models were mostly too aggregated (e.g. manure transport was simulated on regional level) and normative and ignored insights in the actual fertilization behaviour of the farmers.

The objective of the current paper is to present a comprehensive manure allocation model that combines the location choice of processing plants with individual farmer's perceived behaviour on manure production, manure disposition, manure transport and manure supply to possible processors. The methodology of this spatial mathematical programming model is based on a multi-agent simulation system (MP-MAS) applied to a dataset containing the complete farm population in Flanders (38.777 farms).

The paper is worked out as follows. First the modelling aspects of the manure allocation problem are explained with a detailed description of all aspects of manure production, manure spreading, manure processing and manure transport. Next a description of the dataset is given followed by the results section. Finally, some conclusions about the model and the results are discussed. In particular, strengths and shortcomings are discussed of the benefits and pitfalls of spatial mathematical programming for analysis of environmental and regional planning decisions applied to the case of the optimal location of manure processing capacity in Flanders.

2 Modelling the manure allocation problem

2.1 Description of the manure allocation model

Most environmental problems, such as the manure surplus, involve decisions at different levels. At the micro or farm level, the farmer decides to produce manure and to use, to transport or to process it. The aggregation of these numerous decisions results in a manure supply and demand at the macro or regional level. The decisions at micro-level both influence and depend on the conditions at macro or regional level. In other words, manure supply and demand at aggregated level influence and depend on micro level decisions to transport or process. The interaction between farms as decision making agents, i.e. competition for manure disposal space, is thus an important issue. This means that spatial differentiation plays an important role. The manure production and the availability of land to dispose of the manure are regionally diverse and create completely different conditions for micro-level decision makers depending on their location.

Classical mathematical programming models that fail to capture the interaction between agents are thus not able to simulate farmer behaviour in a heterogeneous environment (Berger 2001; Boulanger & Brechet 2005). Obviously, multi-agent-systems (MAS) would be a better simulation option. With MAS artificial micro-worlds can be constructed in which all the parameters, both at the micro and the macro level, can be controlled in a spatial context (Courdier et al. 2002). The micro-level part of the MAS- system is represented by Mathematical Programming (MP) which simulates the farmer as a decision-making subject taking into account legal and other constraints. The use of MP at the core of the decision-making procedure is suitable to capture agent heterogeneity and economic trade-offs while, at the same time it focuses on constraints which have a clear link to policy relevant questions (Schreinemachers & Berger 2006).

MP has also been integrated in MAS by several other researchers, for instance by Berger (2001), Becu et al. (2003), Schreinemachers et al. (2007) and Valbuena et al. (2008). Berger

(2001) and Becu et al. (2003) have applied MAS on the water management problem. Schreinemacher et al. (2007) have used a bio-economic MAS to simulate changes in soilfertility and poverty in Uganda and Valbuena et al.(2008) have simulated changes in land use by means of a MAS. All these former applications deal with the similar problem of individual decisions on utilisation of limited resources where the increase in use of the resource by one decision maker affects the availability of that resource for the other decision makers. The studies deal with small scale applications or are based on samples. To the authors' knowledge, the MP-MAS approach has not yet been applied to a simulation with a large population of more than 38,000 individual decision makers.

The following subsections describe the details of the MP-MAS model. First the the micro-level constraints of decision making are described: production of manure (1.2), disposal of manure on own land (1.3) and manure processing (1.4). This is followed by the description of macro-level interactions between farms through manure exchange by transports (1.5). The final subsection describes the cost calculation of the objective function (1.6).

2.2 Production of manure

Manure production and its nutrient content is very complicated to calculate because these variables not only depend on the number of animals but also on the feeding techniques, the production process, the type and the age of the animals. In a policy context, this complexity of nutrient production estimations is reduced by using generally fixed excretion standards for each type of animal². Deviations from these excretion norms are possible when the farmer can prove that he uses different feeding techniques which causes his animals to excrete less than average, e.g. when making use of nutrient-poor feed. Furthermore, the nutrient production is also corrected for the ammonium losses during storage. In the model, these policy rules are applied for calculating the manure production because the farm primarily acts upon the incentives of the policy based on these calculations.

Despite the fact that the model cannot fully account for farm specific differences in manure volume and quality, the model is able to distinguish the four major types of manure: cattle, pigs, poultry and other. Equation 1 then calculates the manure production of farm f for manure type m (P_{mf}).

$$P_{mf} = \sum_l \sum_p n_{lp} * excr_{lp} \quad \forall l \in m \quad (1)$$

with n_{lp} being the number of animals of animal type l using feeding technique p and $excr_{lp}$ being the corresponding excretion standard per animal.

2.3 Disposing manure on own farmland

A limited amount of the produced nutrients can be spread on the land according to the type of fertilizers, crop category³ and area⁴. With this disposal constraint, the manure decree actually created a system of tradable emission rights for manure (Lauwers et al. 2003). This labelling is justified because manure use, given the imperfect incorporation of nutrient inputs into end products, jointly entails a nutrient emission (Buysse et al. 2008). Different from other systems

²Animal type: combination of species and age

³ The manure regulation has subdivided crops into four different categories (grassland, maize, low nitrogen crops and other crops)

⁴ In the manure regulations distinction is made between general areas and several vulnerable areas (e.g. water, nature, phosphorus saturated areas)

of tradable emission rights, the right (the land) is linked to a fixed location and the emissions (manure) are tradable while for most other emission rights the emissions can not be traded and the rights are not linked to location. In fact, land entails a right to spread manure and both the land and the manure itself are tradable between farms but only the manure can be moved.

In the case of the Flemish manure legislation the total use of nutrients is constrained by four types of emission rights. The use of organic nitrogen (N) and inorganic nitrogen are each bounded by a maximum norm. Moreover the joint use of both nitrogen types is also limited. The fourth emission right limits the use of phosphorus (P_2O_5). In this paper only the three constraints regarding nitrogen use are taken into account because nitrogen is currently the most binding nutrient.

The basic idea of the Flemish manure policy is illustrated in Figure 1.

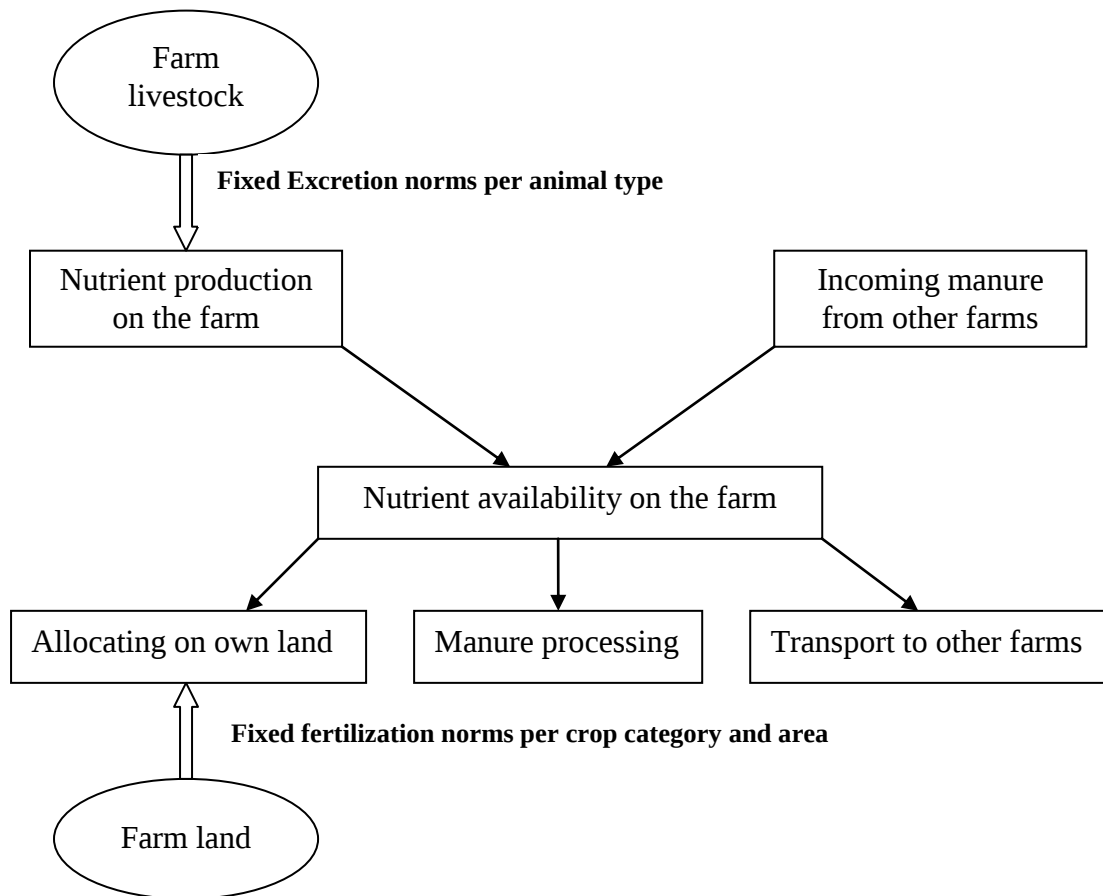


Figure 1: Graphical representation of the structure of the manure legislation

The right to dispose manure on own land depends on the number of hectares and the corresponding fertilization standards. For each combination of crop category and area an fertilization standard is fixed. The general fertilization standards are given in **Fout! Verwijzingsbron niet gevonden..**

The farm' emission rights (R_f) are implemented in the model by equation (2)

$$R_f = \sum_c \sum_a norm_{ca} * h_{ca} \quad (2)$$

where h_{ca} is the number of hectares of the farm per crop category c and area a and $norm_{ca}$ is the fertilization standard for crop category c in area a . The emission rights are calculated for the three different nitrogen quota. R_{of} is the farm emission right for organic nitrogen, R_{if} is the farm emission right for inorganic nitrogen and R_{af} is the farm emission right for total nitrogen.

Equation (2) is expressed as if the available manure disposal space can and would always be met precisely. In reality, emission rights, quota or other constraints are often not exactly binding because of uncertainty about the production and the availability of rights and differences in risk behaviour of farms (Buysse et al., 2008). As it is important to use the actual farmer's fertilizing behaviour in simulations, the available emission rights are calibrated to the current use of these rights. Two calibration calculations are used for the cases of over fertilisation and for the under fertilisation behaviour.

In 2006, many farms disposed more nutrients on their land than legally allowed by their available emission rights because they did not succeed in processing the manure or in exchanging the manure with another farm. Despite the penalties introduced by the manure decree, this over fertilisation still exists because the manure processing capacity has not yet developed sufficiently. For the case of over fertilisation the calibration sets the emission rights equal to the legal emission rights.

Other farms do not completely use their available quota for organic manure despite the fact the surplus farms are willing to pay to manure deficit farms, in some regions more than 300 euro per ha for manure disposal. One of the reasons for not completely using the organic manure quota is that some farmers prefer inorganic to organic fertiliser for certain crops (Feinerman & Komen 2005; Van der Straeten et al. 2008). Because we assume that farmers will continue this behaviour and thus use less organic manure than legally allowed the calibration in the current case sets the emission rights in the model equal to the legal emission rights minus the emission rights that are left unused .

Based on the calibrated emission rights, equations 3 – 5 describe the legal part of disposing manure on own land.

$$\sum_m U_{mf} \leq R_{of} \quad (3)$$

$$U_{if} \leq R_{if} \quad (4)$$

$$\sum_m U_{mf} + U_{if} \leq R_{af} \quad (5)$$

Where U_{mf} is the quantity of manure disposed on the land and U_{if} the quantity of chemical manure used on land. The use of both types of nitrogen is limited to the respective individual emission right and the joint emission right. In the model the farmer can only optimise his fertilization behaviour by changing the organic manure allocation. Because of the fixed chemical nitrogen use, only equation (3) and (5) are relevant. As long as the chemical fertilizer use is low enough, equation (3) is the binding constraint. With higher chemical fertilizer doses, the allocation of organic nitrogen will be limited by equation (5) (Van der Straeten et al. 2008).

2.4 Modelling the manure processing

A second manure allocation option is to process the manure. Distinction has been made between legally obliged processing and market driven processing. Obligatory processing is directly imposed by the manure regulation because the policy does not give the farm the option to compete for on-land disposal. Each farm with a production of more than 10,000 kg

phosphorus and all farms in a municipality with a production of 100 P₂O₅/ha and an own production of more than 7,500 kg phosphorus, are obliged to process some percentage of the farm manure surplus. This percentage depends on the total phosphorus production at the farm. Farms that produce manure without being able to dispose of it within the legal limits on own land or to exchange it with other farms have to process the manure as well. This market driven processing is thus not directly imposed by law but it is, however, a consequence of the manure disposal limits on land.

The introduction of processing as an alternative to disposing on land creates the balancing problem in the manure allocation model. Equation (6) imposes that the allocation problem stays balanced during the simulation procedure. The disposition of manure of type m (U_{mf}) is equal to the sum of the production of the manure at the farm (P_{mf}) plus the incoming manure (I_{mf}) minus the outgoing manure (E_{mf}) minus the processed amount of manure (PR_{mf}). The balance between the two variables that depend on the interaction between other farms, are described in next section.

$$U_{mf} = P_{mf} + I_{mf} - E_{mf} - PR_{mf} \quad (6)$$

2.5 Manure transport

All previous policy driven constraints can be simulated at individual farm level without considering interactions between the farms. However, modelling the transport of manure creates the challenge of simulating interactions between farms.

Modelling the interaction between farms for manure exchange is different from other quota markets such as dairy quota, sugar quota or CO₂-emission rights. Despite the fact that in reality strong rigidities and transaction costs exist in these quota markets, their modelling is often based on a perfect market for quota rights (Mahler 1994; Bureau et al. 1997; Fraser et al. 1997; Brannlund et al. 1998; Alvarez et al. 2006; Van Passel et al. 2006).

The main difference with the aforementioned quotas is that, for the manure problem, emissions are tradable and the rights are locally fixed, while in contrast, for the CO₂-emission rights and most other quota markets, emissions are not tradable while the rights are. Because of the tradability of manure emissions, transport costs of manure play an important role as they create a spatial difference in willingness to pay and thus the market price for manure disposal.

The simulation of each farm in the population and their interactions removes all possible sampling errors. However, it complicates the computation of finding optimal solutions in a large population as the needed computer capacity increases severely. Our dataset of 38,777 farms and 4 types of manure would, for instance, result in a transport matrix of 6,014,622,916 cells. To tackle this large number of cells, a hypothetical transport firm for each municipality was introduced. The transport firm acts as an assembly point where each farm of the respective municipality can offer its excess or collect its demand of manure.

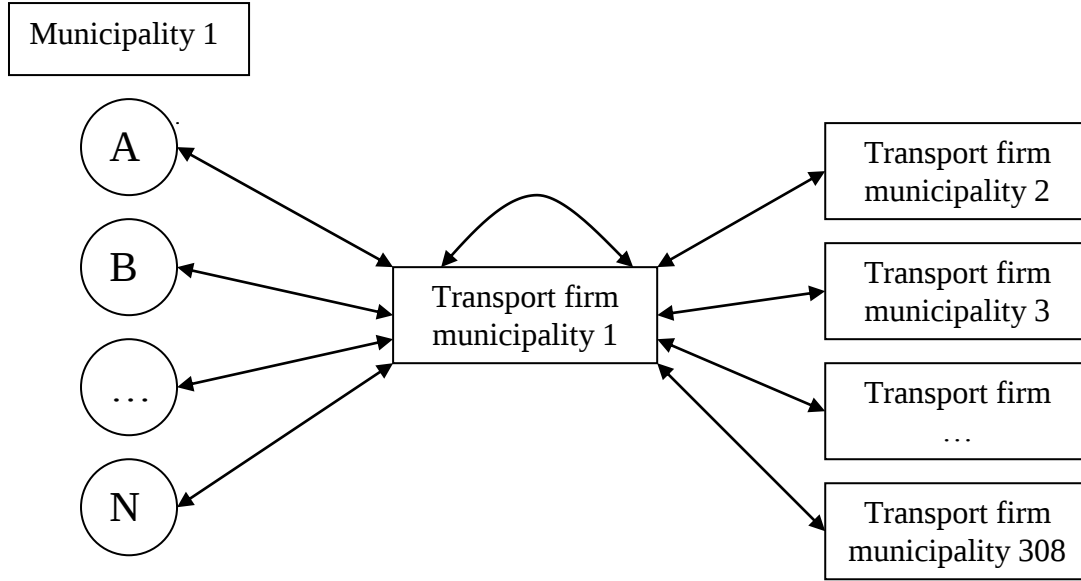


Figure 2: Graphical representation of the working of the municipal transport firm

Figure 2 shows the example for the transport firm of municipality 1. This municipality has n farms. Instead of allowing interaction between these n farms with the whole population, only interaction with the municipal transport firm is taken into account. The interactions with farms of other municipalities are lifted to the higher level where only the interactions between the municipality transport firms are simulated. The model optimises both the transports within the municipality and the transports between the municipalities.

Working with municipal transport firms lowers the number of cells in the transport matrix but does not violate the optimization at farm level. The individual farm still decides whether transport of manure is desirable or not. Once these optimal levels are determined at farm level, the optimization of the exchange of manure between the different municipalities occurs at transport firm level. The transport firm itself is only a tool for allowing optimal exchange over the whole Flemish region and results have proven that the outcome is identical to a simulation where all farms interact directly with each other while the transport matrix contains only 1232×1232 cells.

The transport behaviour of the farms is integrated into the equations (7) to (9).

$$E_{mft} \leq P_{mf} \quad (7)$$

$$\sum_{t_2} T_{mt_1t_2} = \sum_f E_{mft_1} \quad (8)$$

$$\sum_{t_1} T_{mt_1t_2} = \sum_f I_{mft_2} \quad (9)$$

with E_{mft} being the amount of exported manure of manure type m from the farm to transport firm t , I_{mft} the amount of incoming manure of manure type m at the farm from transport firm t and $T_{mt_1t_2}$ the amount of manure of manure type m transported from transport firm t_1 to transport firm t_2 . Constraint (7) prevents the amount of exported manure from exceeding the produced manure of each manure type. Equation (8) imposes that all the exported manure of the individual farms to their respective transport firms is also exported out of these firms to

other transport firms (or the transport firm itself). Equation (9) does the same but at the incoming side. It imposes that the transport firm distributes its total received amount of manure to the respective individual farms.

2.6 Costs calculation

The final step in the model description is defining the objective function. As stated earlier, we assume that the farmer is a cost minimizing agent. The farmer has to choose among the three aforementioned allocation options. All three options involve costs (Table 1).

Table 1: The costs for each allocation option (source: VCM – STIM (2004) and experts)

Allocation options	Used value
Distribution costs (€/m ³)	2.5
Transport costs (€/km/m ³)	0.18
Processing costs (€/m ³)	22.5

Expressed to the volume, the costs are all assumed equal for each manure type. There is, however, a large difference in nitrogen content between the 4 types of manure. As the model is driven by the nutrient standards, the costs per kg of nutrient need to be taken into account (Table 2).

Table 2: Average nitrogen content per m³ (kg N/ m³)

Manure type	Used value (*)
Cattle	4.95
Pigs	6.91
Poultry	15.89
Other	4.14

* within the 4 types of manure the N-content varies among the different animal types. Therefore, the used value is the weighted average N-content of all produced manure in Flanders (source: own calculations)

The allocation results will resort from the differences in costs between the three allocation options and the differences in nitrogen content between the four types of manure.. The distribution option (i.e. disposing the manure on own farm's land) is the cheapest option. When all the available emission rights are used, the farmer will search for available emission rights on other farms. The final option is to process the manure. Manure from poultry has the highest nitrogen content, followed by pigs. Consequently, transport costs and processing costs expressed per kg N will be the lowest for poultry. As a result the farmer will choose to process manure in the following order of manure type: poultry, pigs, other and cattle.

Equations (10) to (12) calculate the costs of the different manure allocation options.

$$C_{uf} = \sum_m U_{mf} * cost_{um} / N_content_m \quad (10)$$

$$C_{PRf} = \sum_m PR_{mf} * cost_{PRm} / N_content_m \quad (11)$$

$$C_{t_1} = \sum_{t_2} \sum_m T_{mt_1t_2} * cost_{em} * distance_{t_1t_2} / N_content_m \quad (12)$$

with $cost_{um}$ being the costs to dispose of 1 m³ manure of type m on own land, $cost_{PRm}$ the costs to process 1 m³ manure of type m , $cost_{em}$ the costs to transport 1 m³ manure of type m over 1 km and $N_content_m$ the N content per m³ of manure of type m . C_{uf} and C_{PRf} are the total disposal and processing costs of the farm, respectively, while C_t is the total cost of the transport firm t .

The final phase in constructing the model is to define the objective function (equation (13)).

$$\underset{U_{mf}, V_{mf}, E_{mf}}{\text{Min}} \text{ costs} = \sum_f C_{uf} + C_{PRf} + \sum_t C_t \quad (13)$$

3 Data

The data base is set up by the Flemish Land Agency (FLA). It contains all variables related to production, transactions, acquisitions and use of nutrients for each Flemish farm individually. The total dataset consists 60,577 farms over a period of seven years (2000-2006) with a total of 311,430 unbalanced panel observations. For the current paper only farms with more than 2 hectares or a nutrient production of more than 300 kg phosphorus in the year 2006 were taken into account. The used sample consists of 38,777 farms. Table 3 shows the aggregated figures of the total emission rights and the nutrient excretion in the sample.

Table 3: Aggregated figures regarding the production and use of organic nitrogen in Flanders in 2006 (source: own calculations)

variable	Value
Total used emission right for organic nitrogen (kg N)	102,093,402
Actual production of organic nitrogen (kg N)	128,495,690
Production surplus of organic nitrogen (kg N)	26,402,288

In 2006 102 million emission rights for organic nitrogen (kg N) are used in practice. This means 72.5% of the theoretically available emission rights for organic nitrogen. In practice, Flanders is not able to dispose of 26.4 million kg out of these 102 million kg of nitrogen on farmland. As only 16.3 million kg is processed or exported, there was an over fertilization of 10.1 million kg nitrogen exists.

4 Model results

The proposed model and the dataset can be used for different applications in manure management choices, policy evaluations and investment decision support analysis. First, the model is used to evaluate policy alternatives and their impact on costs of manure allocation. Second, the model supports investment decisions by advising on location and type of manure processing. The simulations compare the existing manure processing capacity with the optimal demand. The model results indicate whether the development of manure processing capacity so far is efficiently located. Taking the already existing capacity into account new simulations show where more investments in processing capacity are needed. Finally, the model produces results for an indicator that creates transparency in the manure transport and processing market.

4.1 Policy analysis

The first applications of the model are straightforward calculations of the impact of policy choices on sector parameters. The effect of the legally obliged manure processing on the total manure allocation costs is taken here as an example. The manure policy tries to cool down the manure market by imposing a processing obligation on the largest manure surplus farms. Moreover this enables the policy makers to steer the development of manure processing. The model is used to investigate whether this attempt is cost effective. The total cost for manure allocation with the obliged manure processing is compared to the situation where only market driven processing is simulated (Table 5 and Table 6).

Table 4: the simulated allocation choices compared between market driven manure processing and legally obliged processing

	cattle	pig	poultry	other
Nitrogen production	67,692,272	45,660,663	12,707,607	2,435,148
<i>Market driven processing option</i>				
Simulated total disposed N	67,692,272	31,305,954	660,028	2,435,148
Simulated transported N	10,525,939	26,336,283	1,048,555	316,072
Simulated (market driven) processed N	0	14,354,708	12,047,579	0
<i>Legally obliged processing option</i>				
Simulated total disposed N	67,162,008	31,311,969	1,191,750	2,427,675
Simulated transported N	7,484,268	18,985,347	1,159,665	575,205
Obligatory processed N	530,264	7,143,193	4,928,395	7,473
Simulated (market driven) processed N	0	7,205,501	6,587,461	

Table 5: total costs per allocation option compared between market driven manure processing and legally obliged processing

	No legally obliged processing	Legally obliged processing
Disposal costs	47,088,682	46,902,192
Transport costs	8,967,519	9,874,928
Processing costs	63,800,281	65,478,693
Total costs	119,856,482	122,255,812

In the case of market driven processing, the individual decision makers in the model will optimise the location and the type of manure processing to meet the nitrogen fertilization restrictions. This increased freedom for the individual decision makers lowers the total cost of manure allocation with 2,399,330 euro with the same amount of nitrogen used on the land according to the fertilization standards. The model shows that the policy indicator for steering manure processing is thus not at all efficient.

More than 20% of the nitrogen from manure has to be processed or exported, which creates also a great cost for the manure surplus farms. Therefore, it is important to search for the most cost efficient policy and investments for optimal manure allocation. Current subsection has shown how the policy could be improved, the next subsection shows how the use of MP-MAS as a planning instrument can help investors to obtain more benefits from manure processing by the development of the best type of plant on the optimal location.

4.2 Investment decision support analysis

In 2006, the total demand of manure processing was 26.40 million kg nitrogen (Table 5: sum of simulated obligatory and market driven processed N) while only 16.3 million kg nitrogen was effectively processed. This gap implies that there is an extra demand for manure

processing of 10.1 million kg nitrogen. The model enables investors to determine where extra processing capacity is most desirable according to the stated objective.

The lowest possible costs for the farmer (cost-efficient) and the highest benefit from the manure processor is reached by optimizing the location of the processing systems and the type of manure that can be processed. Implementing capacity close to the farms demanding extra processing capacity lowers the transport distance to the processing system. The choice of type of manure is also very important because processing costs differ significantly among manure types.

The results of model simulations of the optimal manure processing locations given the current policy are shown in figure 3. The figure shows actually the municipal manure surplus⁵ and thus the processing demand. In total 26.40 million kg must be processed in Flanders including both legally obliged and market driven manure processing. The location of the obliged processing is driven by the policy criteria and is spread quite evenly in Flanders. The market driven processing is only driven by the maximum fertilization limits on the land, production and economic motives of minimisation of transport and processing costs.

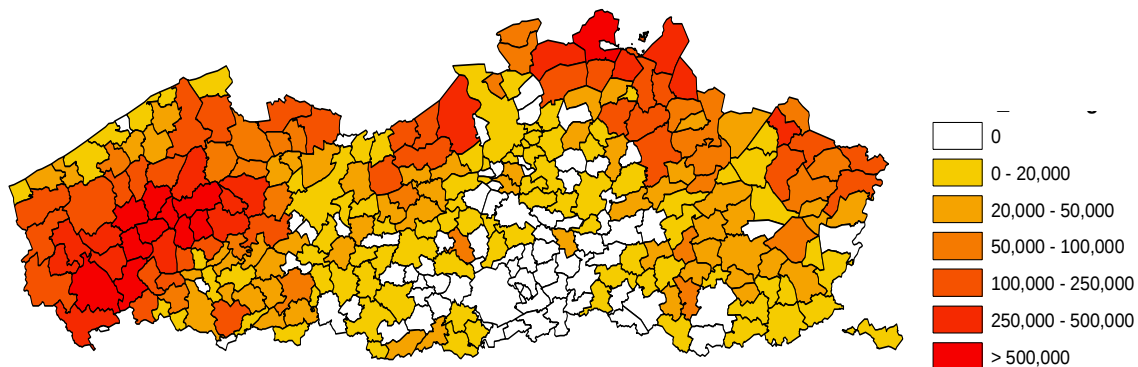


Figure 3: The simulated municipal demand for manure processing in 2006 (kg N)

However, the true situation differs from the optimal situation. A part of the demand for manure processing, illustrated in Figure 4, has already been realised by previous investments, not necessarily following the optimal allocation pattern. Currently, the operational processing capacity is almost 16.4 million kg N in Flanders.

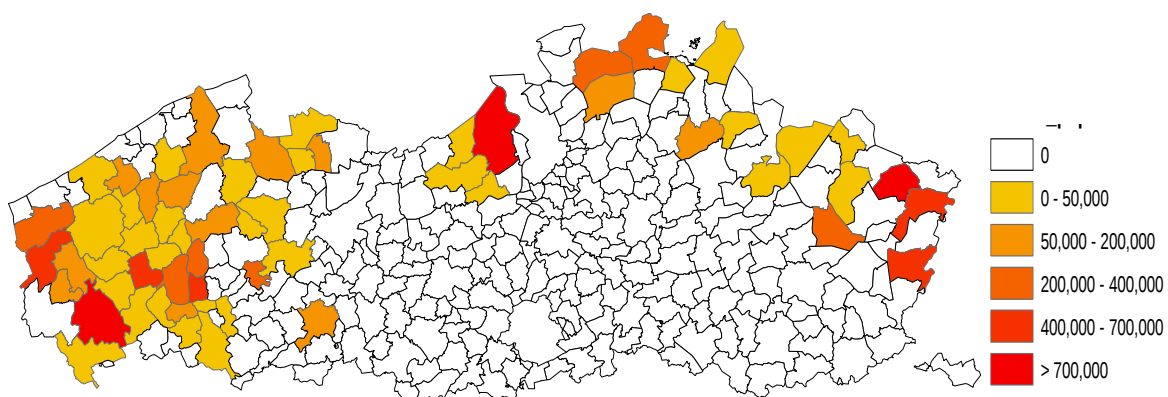


Figure 4: The actual municipal processing capacity in 2006 (kg N)

Given the current situation, the new optimal location pattern must be updated. Therefore, the current capacity is brought into the model and a new simulation procedure is performed. The

⁵ Surplus manure : manure which can not be disposed on own land or transported to other farms

result of the second simulation is given in figure 5. Figure 5 shows that currently the best investment in terms of cost minimisation is the development of a pig manure processing plant in the centre of West-Flanders.

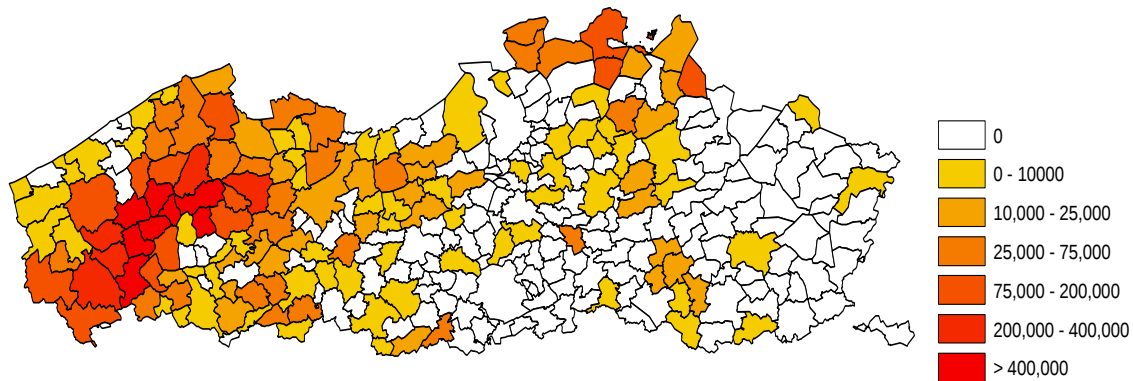


Figure 5: The simulated extra manure processing capacity per municipality in 2006 (kg N)

4.3 Regional manure pressure indicator

The reasons why the legally imposed processing is far from optimality (allocation costs: + 2%) is to be found in the criteria on which obligatory manure processing is based. The current policy, steering the obligatory manure processing, uses an indicator based on a simple comparison of animal production and the number of hectares. This indicator is not very precise because it ignores the possibility of transport to neighbouring regions and disregards the fertilization behaviour of the farms.

The needed processing capacity shown in figure 5 is already a much better indicator with more valuable information because it takes transports, type of manure and actual fertilising behaviour into account. However, figure 5 does not tell the decision maker how much the investment in processing capacity may cost and how much an individual farm may pay for manure disposal on land.

Therefore, the model produces also a regional manure pressure indicator (RMPI). The RMPI is the dual value of the manure allocation equation (3) of the MP-MAS manure allocation model presented in this paper. This dual value gives the marginal cost of disposing 1 kg nitrogen. In regions with highly concentrated animal production and relatively low number of emission rights in their surroundings, this cost (dual value or regional manure pressure) is high. When competition for free emission rights is rather low, the regional manure pressure will be low as well. The regional manure pressure is given in figure 6.

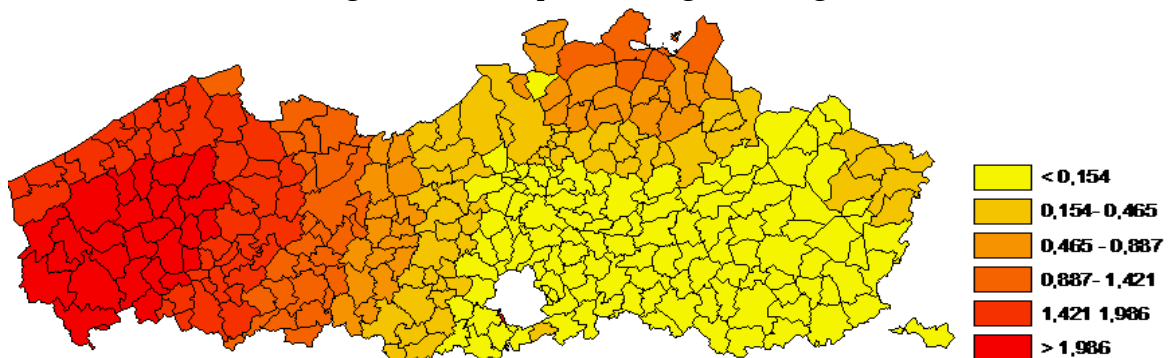


Figure 6: Regional manure pressure in Flanders (2006) (€/kg)

The RPMI is expressed in monetary terms and is therefore very relevant additional information for policy makers and manure processing investors. The RPMI shows the spatial distribution of the willingness to pay for manure processing. While figure 5 indicates for which capacity a manure processing demand exists, the RPMI also indicates the regional impact of the demand in monetary terms. In this way investors may decide to develop a larger capacity in a certain municipality than needed but fulfil the demand of farms from neighbouring municipalities with also a high RPMI.

The RPMI can therefore also provide market information on transport of manure between farms. Better market information can make the market of transports more transparent because it clearly shows the maximum cost of disposing manure in each region.

5 Conclusions

The paper presents a model to simulate the impact and policies of spatially heterogeneous environmental pollution. The model is applied to the case of manure surplus in Flanders.

As a result of the Nitrates Directive, manure allocation has been regulated very strictly by the Flemish government. The farmer has three possibilities to get rid of his manure: disposing on own land, transporting it to other farms and processing manure. The first two options are limited because of total emission rights on all Flemish farms. Manure is seen as an emission while land with the corresponding fertilization norm is seen as the right. In contrast to other emission rights, the right (land) is locally fixed and the emissions (manure) are tradable between farms.

The environmental management of manure in Flanders has three typical features:

- i) The impact of environmental policies depends on interactions between the individual decision makers resulting in an interplay between micro (farm) and macro (regional) level. The decisions at micro level both influence and depend on the situation at macro level. This has led to a competition between farms for manure disposal space.
- ii) Environmental emissions are spatially diverse. The spatial pattern of manure emission from highly concentrated livestock production has developed from the reliance on imported feed. Pig and poultry farms located themselves near to sea-ports resulting in a high manure pressure in these regions.
- iii) Emission abatement technology is heterogeneous. The heterogeneity in manure abatement is driven by the differences in the sources of manure (type of animals) and the available sinks for manure (type of land and crops).

The paper shows that these typical features of environmental management problems can be tackled by MP-MAS models. The manure allocation model works for the entire Flemish farm population (38,777 farms). The model is able to simulate the manure allocation behaviour of the individual farm in a normative way. The model is illustrated with an application on the dataset to simulate manure allocation management. First, the model is used to make policy evaluations. The effectiveness and efficiency of the legally obliged manure processing regulation is analysed. Next, the model is used to analyse investment decisions by showing the quantity of demand for manure processing in a spatial context. Finally, the manure pressure indicator is introduced to help both policy makers and private decision makers by

providing market information on the spatial differentiation of the cost of environmental pollution.

The results show that the current policy of steering the manure processing capacity is far from optimal, since the introduction of obligatory manure processing has an additional total cost of 2,399,330 euro without any environmental benefits. With respect to investments in new manure processing capacity, the model clearly indicates the regions (e.g. West-Flanders) that need additional investments. The possible benefits from these investments can be derived from the regional manure pressure indicator because it gives in monetary terms the willingness to pay for manure disposal. The regional manure pressure indicator should also improve the market transparency to ameliorate the management of transport and processing in order to reach the same environmental objective in a more efficient way.

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