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Bottom-up methodologies for the modeling and upscaling of farm Nitrogen losses in European landscapes

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Abstract: This paper presents bottom-up scaling methodologies, implemented in the MEA-Scope strategic research project, and in the NitroEurope landscape level component. Both projects are based on a bottom-up approach, where farm information are collected for landscapes in Germany, Slovakia, Poland, France, Hungary, Italy, Scotland, The Netherlands and Denmark; and landscape level impacts of the Model for European Agriculture (MEA) are assessed. This paper is about the upscaling from farm to landscape level, and focuses on the modelling of Nitrogen surplus from agriculture as an indicator for water pollution. It is demonstrated in detail how farm information from the Danish landscape is upscaled for such landscape level analyses, using the EU Integrated Area Control System (IACS) and GIS. Subsequently, farm N-surpluses, upscaled for each of the other MEA-scope landscapes, are also presented, and different upscaling pathways are reviewed. Based on the results, advantages in the bottom-up approaches applied are emphasized. It is concluded, that bottom-up methods for upscaling are needed to convey information from research to decision-makers, and that it is important to specifically address the scale issue within the cycle of strategic research, where an iterative interaction between researchers and decision-makers is carried out.

Keywords: Scaling, farm, landscape, Land Parcel Information System (LPIS), Geographical Information System (GIS), bottom-up modeling.

1. INTRODUCTION

Strategic research is characterized by an iterative interaction between researchers and decision-makers [Bierkens *et al.* 2000]; denoted *"The Cycle of Strategic Research"* (Figure 1). The MEA-scope strategic research project (www.MEA-scope.eu), from which results are presented in this paper, is a good example of such interaction. In this project landscape level impacts of the Model for European Agriculture (MEA) are assessed, and within this context, the present paper focus on one of the major challenges within the cycle of strategic research, namely the problem of scaling research results to the scale, where information is needed by decision makers [Dalgaard *et al.* 2003]. This is exemplified with results from the MEA-scope project, as presented in Dalgaard et al. [2008], and with perspectives for the NitroEurope Integrated EU research project (www.NitroEurope.eu).

In MEA-scope, the initial question was formulated by The European Commission, requesting "an integrated framework for the assessment of the multifunctionality impacts of the EU common agricultural and rural development policy reform" (www.MEA-scope.org). The consortium of research institutions behind MEA-scope responded to this question with a project formulation, focussing on an impact assessment of the

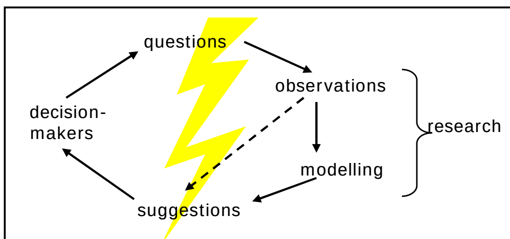

Figure 1. The cycle of strategic research [Bierkens et al. 2000]. The lightening symbolizes the gap between the scale where decision makers operate, and the scale where observations and modeling typically are carried out by researchers.

agricultural production and its multiple functions in seven landscapes selected. During end-user workshops in Brussels, the research progress was presented. Based on feed-backs from these meetings and from internal project workshops, data collection and modelling approaches were designed [Müller and Piorr 2008].

Since landscapes can be conceived as a conglomerate of different homogenous units [Forman and Godron 1986], of which farming is a very important part, it is vital from the perspective of multifunctionality to represent landscapes in a manner which reflects their multifunctional nature [Brandt and Vejre 2004; Vejre *et al.* 2007].

The upscaling procedure can be said to aim at establishing a representation of landscape functions, building on the farm level simulations, which aims to serve two purposes: adaptation of the knowledge generated in the project to the needs of the potential end users, in addition to pinpointing areas in need of further research. It can be expressed as in the Figure 2, which depicts scaling as a procedure which aims at balancing both research and policy needs.

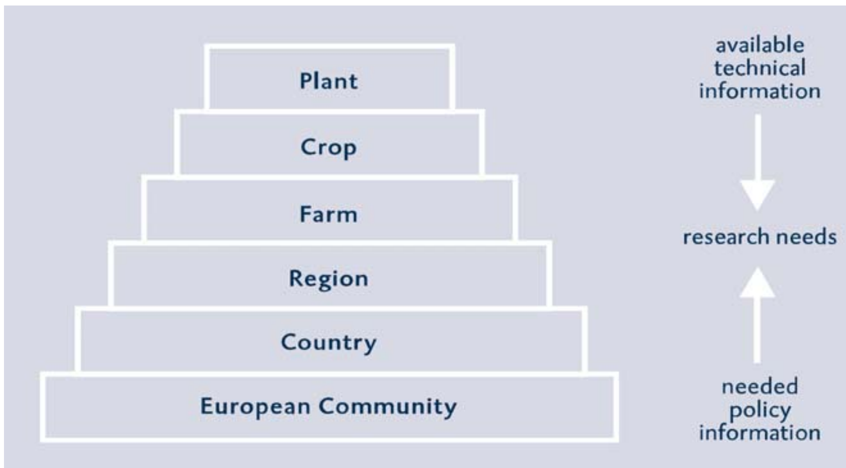

Figure 2. Levels of scale and research needs [van Latesteijn 1998, 1999]

Dalgaard *et al.* [2003] has dealt with the interactive process of setting the appropriate scale relative to the needs of decision-makers. The framework derived from this work is summarised in the table below.

Table 1. General upscaling framework to support and evaluate the conveyance of information between science and decision-makers [Dalgaard et al. 2003]. See the text for further explanation

Criteria 1. Define the decision-maker and the problem and the scale at which the decision-maker needs information.
Criteria 2. Determine on which scales information regarding this problem is available and collect the relevant information.
Criteria 3. Create a hypothesis of how existing information, identified in criteria 2, can be transformed to the scale needed for decision-making, identified in criteria 1. First try with simple linear scaling procedures, and after having tested them in criteria 4, try more complicated, non-linear or hierarchical scaling procedures.
Criteria 4. Test the hypothesis of criteria 3 with independently sampled decision-maker scale information. If the hypothesis is rejected, try with a new hypothesis or seek new information, which can be transformed to the decision-maker scale.

In the MEA-Scope context, application of this upscaling framework could be expressed with the following four criteria analyses: 1. Identify the most relevant landscape functions, required by decision-makers for the specific landscape: for example the present paper focus on nitrogen surplus and the related provision of clean drinking water and non-eutrophicated surface waters. This is especially an important function in the Danish landscape [Schrader et al. 2008]. 2. Review and collect relevant farm and landscape level data. 3. Scaling from farm to landscape: Mapping indicators via GIS-data, farm-data geo-coding, farm type modelling and regionalisation 4. Test the upscaled results

As the above framework incorporates insights from systems theory [Spedding 1979; Altieri 1995; Gliessman 1998; Checkland 1999], a distinction is made between different types of upscaling: linear, non-linear and hierarchical [Dalgaard et al. 2003]. Linear upscaling refers to a case where upscaling is simply a matter of aggregation of lower level data, whereas non-linear and hierarchical upscaling takes emergent factors into account. A practical example, which is used in the article quoted above, is the influence of increasing field size on farm level fuel use. Another example is the results presented in the present paper, and the non-linear relationship between nitrogen surplus and livestock density (Figure 8). Non-linear upscaling addresses issues within relative fixed boundaries of the system in question, whereas hierarchical scaling can be considered an extended case of non-linear scaling, since it deals with the consequences of extending system boundaries. One practical example is when scale is increased from farm to landscape level. The consequence is that scaling must be approached in a reflective and iterative way, taking into consideration many different levels of organisation and the different temporal and spatial scales that might be of importance for the long-term sustainability of the system as a whole [Dalgaard et al. 2006; Fresco and Kroonenberg 1992].

This paper presents upscaling methodologies, implemented in the MEA-scope strategic research project, and perspectives for the NitroEurope landscape level component. MEA-scope is based on a bottom-up approach, where farm information are collected for landscapes in Germany, Slovakia, Poland, France, Hungary, Italy and Denmark. The NitroEurope landscape level component is based on data collection from landscapes in Scotland, France, Poland, Italy, The Netherlands and Denmark. This paper is about the upscaling from farm to landscape level, and focuses on the modelling of Nitrogen surplus and Nitrogen losses from agriculture as indicators for water pollution. Based on Dalgaard *et al.* [2008], it is demonstrated in detail how farm information from the Danish landscape is upscaled for such landscape level analysis, using the EU Integrated Area Control System (IACS), The Land Parcel Information System (LPIS) obligatory for all member states, and geographical systems analysis (GIS). Subsequently, farm N-surpluses, upscaled for other landscapes, are also presented, and different upscaling pathways are reviewed. Based on the results, advantages in the bottom-up approaches applied are emphasized.

2. MATERIALS AND METHODS

There are two main approaches to derive landscape level farm information for the use in decision-making (Figure 3). The first approach is a top-down approach where information from national or regional farm statistics are disaggregated (downscaled) to the landscape level. Recent examples of such approaches are outlined in Leip et al. [2007]. In MEA-Scope, we use the second approach, where landscape level farm information is derived bottom-up. This means that the landscape level information is aggregated (upscaled) from farm information required locally within the actual landscape (for example from local farm surveys and detailed GIS land use maps in combination with maps over the placements of specific farms within a landscape, see below).

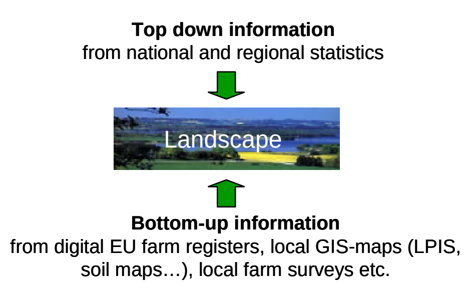

Figure 3. Sources for top-down versus bottom-up derivation of farm information for landscape level studies

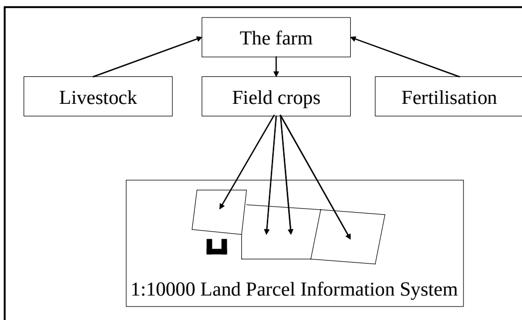

Figure 4. Illustration of the types of digital farm data registered in EU member states for the control of farm subsidies paid. Via the obligatory Land Parcel Information System (LPIS) these data can be geo-referenced and mapped in GIS. It is mandatory to include livestock and field crop registrations, while fertilisation practices are only registered in some member states

In MEA-Scope we apply two different levels of bottom-up landscape farm mapping: 1) The first level includes "real farm maps" required from the mandatory EU digital farm registers, and 2) the second level relies on "proxy farm maps", derived from local farm surveys and GIS-information.

While Ungaro et al. [2008] and Damgaard et al. [2008a] focus on the second level of farm mapping, the present paper uses the first level "real farm maps" to exemplify points regarding scaling. The "real farm maps" are derived from the mandatory EU digital farm registers. According to The European Commission [1992] all EU member states are required to set-up an Integrated Area and Control System (IACS), where subsidy payments are digitally registered. Moreover, a GIS-based Land Parcel Information System (LPIS), to which the subsidy payments can be geographically related, must be established (Figure 4).

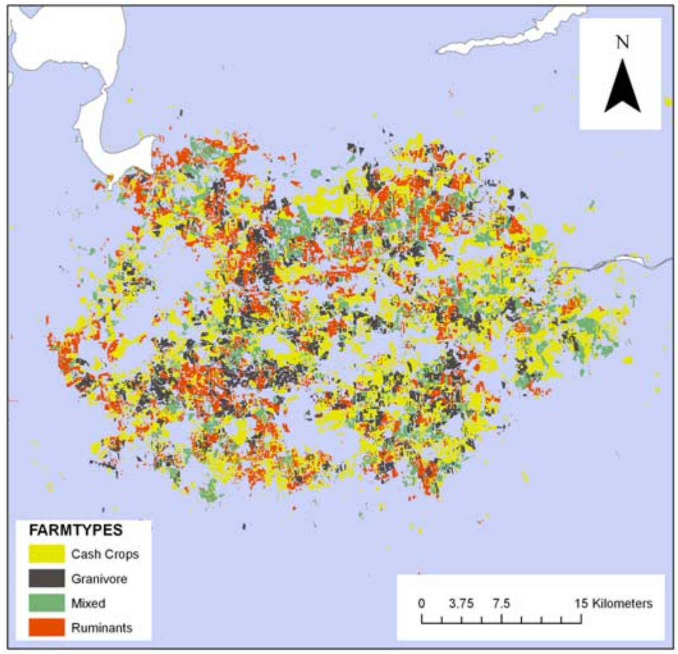

Figure 5. "Real farm map" for the Danish study landscape in year 2002. Each of the in total 1.871 farm has been classified into four main types, according to the EUROSTAT/FADN methods (McClintock 1989; Dalgaard et al. 2002b).

In MEA-Scope, IACS and LPIS data have been available for the study landscapes in Denmark and Slovakia. From this information maps showing the areas belonging to each farm within each land parcel can be constructed. Figure 5 shows an example of such map, where each of the 1.871 farms in the Danish study landscape in year 2002 has been classified into four main types, according to the European Farm Accountancy Data Network, FADN and EUROSTAT methods [McClintock 1989, Dalgaard et al. 2002b].

There are two different pathways for the upscaling of bottom-up farm level information for landscape level modelling [Marshall et al. 1998; Kjeldsen et al. 2006]. In the first pathway, modelling is initially carried out

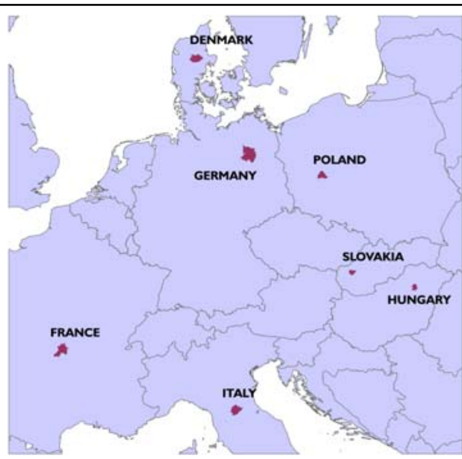

Figure 6. The geographical location of the seven MEA-Scope study landscapes.

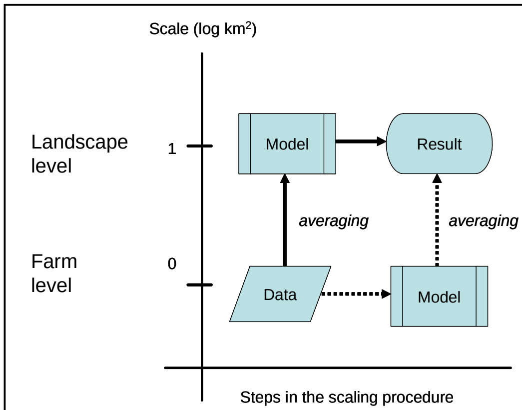

Figure 7. The two pathways for the upscaling of farm information and model results from farm to landscape level: 1) modelling before aggregation, and 2) vice versa (based on Kjeldsen et al. 2006).

on the single farm data, before aggregating the model results to the landscape level, while in the second pathway the farm information is averaged before modelling (Figure 7).

In the present paper it is demonstrated how these two pathways can lead to significantly different results. This is demonstrated using the Farm-N model (www.Farm-N.dk, www.Farm-N.dk/farmNtool) to simulate farm nitrogen (N) surpluses for the Danish study landscape in 2002. With this model, the farm N-surplus is calculated in kg N/ha/yr as N-inputs (mineral fertilizer, manure, feed, straw, seeds and animals bought + N fixed and N deposited from the atmosphere) minus N-outputs (cash-crops, animal prod-ucts, milk, manure, and feed and straw sold). For more details see Dalgaard et al. [2007b].

In total, the MEA-Scope model framework is applied to seven European landscapes (Figure 6). The project focussed on beef farming, and the landscapes were selected to include a significant part of the land with grassing livestock. The hypothesis was that these systems carried a special potential to contribute to a more sustainable development. Additional key figures for agriculture and land use in these landscapes can be found in Dalgaard et al. [2007a] and at http://mea-scope.eu/.

3. RESULTS

Based on the bottom-up farm information available, the nitrogen surpluses are modelled for all the 1.871 farms in the Danish study area, and plotted against the livestock density (Figure 8).

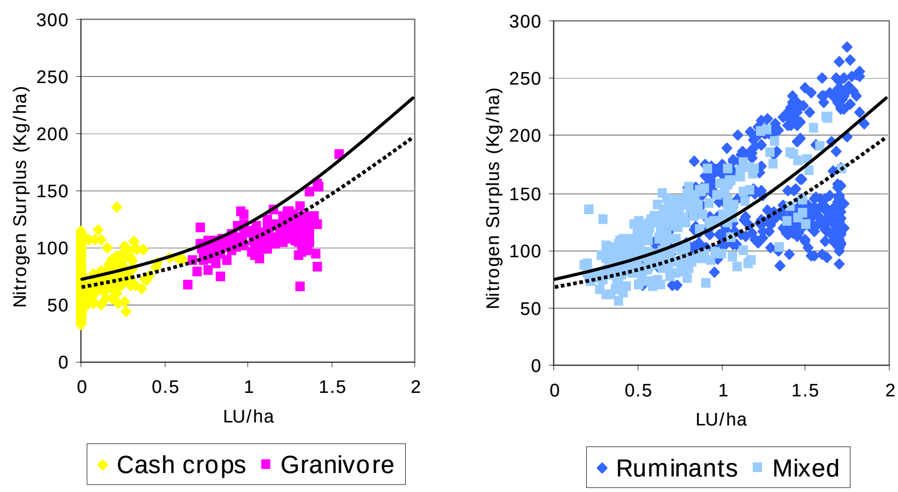

Figure 8. Nitrogen surplus estimated with the Farm-N model for each of the 1.871 farms within the Danish study landscape in year 2002, and plotted against the livestock density in livestock units (LU) per ha. The farms are divided into the four main farm types of Figure 5. The dotted lines show the regression for all farms modelled ($y= 64\ e^{[0.57x]}$), compared to the non-dotted $y= 77\ e^{[0.56x]}$ regression from an independent empirical study of 41 farms within the study area (Dalgaard et al. 2002a).

In correspondence with the statistically significant relationship, derived empirically by Dalgaard et al. [2002a], the model results show a non-linear relationship between nitrogen surplus and livestock density (Figure 8). The model results show lower estimated N-surpluses ($y= 64\ e^{[0.57x]}$) than the empirical study ($y= 77\ e^{[0.56x]}$), a result which could be expected because of increased manure N utilisation rates over time. I.e. the model calculations, which are for the year 2002, assume higher rates for the utilisation of N in livestock manures than those generally anticipated on farms from the empirical study from year 1994-1998. Moreover, the empirical study included farms with higher livestock densities (up to 2.9 LU/ha) than the present study from 2002, and as a consequence of the non-linear relationship, a relatively higher N-surplus for these farms can be anticipated.

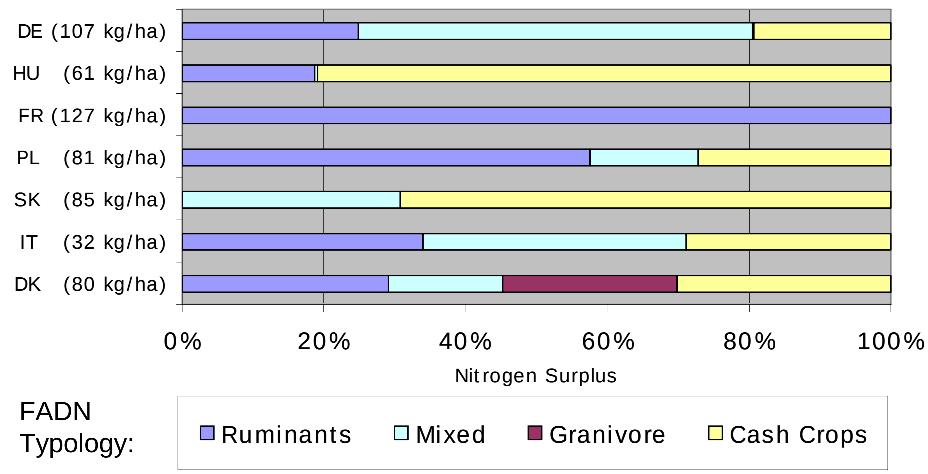

Figure 9. Upscaled farm nitrogen surpluses from the seven MEA-Scope study landscapes in Germany (DE), Hungary (HU), France (FR), Poland (PL), Slovakia (SK), Italy (IT) and Denmark (DK). The N surpluses for all farms in each of the landscapes are modelled with the farm-N model, and the results are upscaled to the landscape level using the pathway 1 approach of figure 7. Finally, the results are summarised in the four main EUROSTAT farm type classes of figure 5, and for each study landscape the average kg N-surplus per ha is specified in brackets.

In summary, the non-linear relationship indicates that the bottom-up information approach applied in the present study results in another N-surplus result than if a top-down approach was applied. If a top-down approach had been applied, the farm N-surpluses would namely not have been modelled for each farm separately (pathway 1 in Figure 7), but for averaged groups of farms (pathway 2 in Figure 7). For example according to the non-linear relationship in Figure 8, farms with 0, 1 and 2 LU/ha would typically yield around 64 $e^{[0.57x0]}$)= 64, 64 $e^{[0.57x1]}$)= 113 and 64 $e^{[0.57x2]}$)= 200 kg N-surplus per ha per year, respectively; according to the regression line (Figure 8). However, the average of (64+200)/2= 132 is not equal to 113, and a top-down approach following the pathway 2 scaling procedure would in this case typically overestimate the total N-surplus from a group of farms.

Another important advantage in using a bottom-up approach based on single farm data is the possibility for detailed mapping and geographical analysis. Figure 10 shows an example of such mapping based on the farm N-surpluses of Figure 8 and the “real farm map” of Figure 5. With such map it is possible to identify nitrogen surplus hot-spots in the landscape, and to make overlay analysis with maps over Natura 2000 sites, groundwater protection areas etc. Finally, explicit mapping of the farming structure enables advanced analyses of the relations between farm structural development and environmental

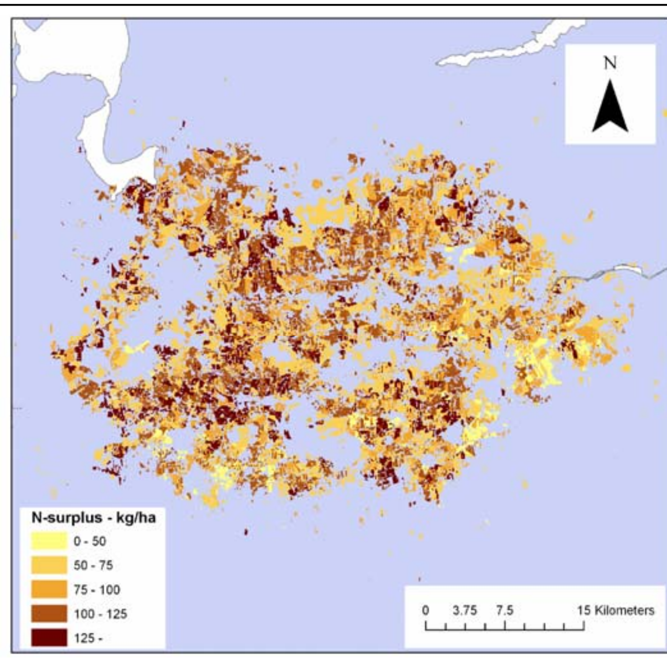

Figure 10. Farm Nitrogen surplus map over the 1.871 farms in the Danish study landscape in year 2002. The mapped N-surplus values are equal to those presented in the scatter plot of figure 8.

effects of agriculture in the form of nitrogen pollution. However, this is out of the scope with the present paper, and must be left for future studies.

Based on the bottom-up farm information acquired in the seven MEA-Scope study landscapes of Figure 6, the N surpluses for all farms in each of the landscapes are modelled with the farm-N model, and the results are upscaled to the landscape level using the pathway 1 approach of Figure 7. Figure 9 shows the summarised nitrogen surplus results from the seven MEA-Scope landscapes in year 2002, distributed on the four EUROSTAT main farm types of Figure 5: ruminants (mainly cattle), granivores (mainly pigs), mixed farms and cash crop farms. In summary, the N-surplus was highest on farms with ruminant and granivores (at average 108 kg N/ha and 121 kg N/ha, respectively), and lowest on cash-crop and mixed farms (at average 74 kg N/ha and 61 kg N/ha, respectively), but with a large variation both within and between landscapes (for example farms with ruminants in the French landscape showed an average N-surplus of 127 kg N/ha, compared to an N-surplus of 85 kg N/ha in the Polish landscape). In Figure 9 the differences between landscapes are indicated with the average kg N-surplus per ha, specified in brackets for each study landscape. In line with the results of Figure 8, the landscapes in France, Poland, Germany and Denmark with a relatively high share of ruminant farms, have a high average N-surplus. With exception of the Italian landscape, where the livestock density of this category is quite low, this is because these farms generally have a high livestock density and consequently also a high Nitrogen surplus. Moreover, in line with the results presented in Figure 8, the variation in N-surplus was highest on ruminant farms, including a significant proportion of grassing livestock. Thereby, because of the large variation in N-surpluses, the potential for reducing the N-surplus also seems to be the highest within this farm category. This corresponds well to the hypothesis of the MEA-scope project, that these systems have a special potential to contribute to a more sustainable development; and in this case a reduction in the N-surplus from agriculture.

5. CONCLUSIONS

The results presented in this paper illustrate clear advantages in using the bottom-up approaches applied in MEA-Scope and Nitro-Europe, compared to the more usual top-down approaches. Moreover, advantages in upscaling of model results from farm to landscape level, using the first pathway of Figure 7 are illustrated, and dangers of the second pathway are emphasized.

In reality geo-referenced bottom-up farm information is often not readily available at the landscape level all over Europe. This makes the creation of detailed maps like Figure 5 and Figure 9 difficult, and a combination of the first and the second upscaling pathway of Figure 7 must be applied. Actually, such aggregation is also applied in MEA-Scope, where bottom-up farm information for “real farm mapping” has only been available for Slovakia and Denmark, and where farm group information has been applied in some part of the modelling instead of farm specific information. It is important to be aware of the potential problems of applying such compromises. It is our hope that the present paper can draw attention to some of the key problems in scaling from farm to landscape, and help to enlighten some of the errors that might appear when doing the needed compromises in the scaling procedures. In Denmark, “real farm maps” are now being used nationally to produce detailed maps over the risk for N-losses from farming, and in the years to come these maps will be used to evaluate the goals setup according the EU Water Framework Directive (Kronvang et al., 2008). Also, the Farm-N model, is now is used nationally to account N-losses from farms which increase their livestock production significantly, and it will be interesting to follow to which degree the issues discussed in this paper will be integrated in the practical procedures for the landscape scale evaluation of farm Nitrogen losses.

To finally conclude on the nature of upscaling, it can be defined as an iterative process, where the actual outcome cannot be seen in isolation from the policy needs formulated by the end users. Thus, end user workshops like the ones carried out in MEA-Scope, and the scaling of information within the Figure 1 cycle of strategic research produce a very important input to this process.

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