Exploring multifunctionality and environmental impact of dairy farming systems

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Abstract

The multifunctional performance and environmental impact of dairy farming systems in Norway are studied using a model that combines ideas from mathematical programming and multi-criteria analysis. The first step is to identify variables with importance for multifunctionality. The different combinations of these variables are then examined using an algorithm that steps through the different combinations and generates a set of farming systems that are compared using multi-criteria analysis. This approach makes it possible to compare different farming systems with respect to several criteria. Examples of criteria are net farm income, labour input, N loss from soil, and the impact of grassland management on biodiversity. To quantify and evaluate the latter criteria, the biodiversity management index has been developed. The biodiversity management index is defined as a function of disturbance and nitrogen input to the system. For pastures, disturbance is in turn defined as a function of biomass removed by grazing and grazing frequency. The model presented is flexible, new aspects of multifunctionality can easily be integrated, and the model can be scaled up from farm to or regional level. The model is still under development but some preliminary results are presented and possibilities for further development of the model are discusses.

1. Introduction

1.1 Structural change and multifunctionality in agriculture

European agriculture has been through large changes during the last 100 years with important implications for both productivity and the environmental impact of agriculture (Stoate et al. 2009). In Norway, agriculture has experienced changes similar to other countries in northern Europe but many of the changes have appeared later in Norway than in e.g. Finland and Sweden (Emanuelsson 2009). Although there have been large structural changes in Norwegian agriculture since the 1950s and -60s, the average farm in Norway is still relatively small at a European scale (Almås & Brobakk 2012). From 2000 to 2010 the number of dairy farms was reduced from 20 000 to 11 000 and in 2010 the average Norwegian dairy farm had approximately 32 ha agricultural land, a milk quota of 132 000 kg and about 21 dairy cows (Statistics Norway 2012). Land tenancy and cooperation between dairy farmers who maintain ownership of land but merge herds and farm operations in a single business have become more common and is an important component of the structural change today (Almås & Brobakk 2012). The structural changes have implications for the farming systems and the environmental impact of agriculture (Stoate et al. 2009; Mandryk et al. 2012). Nevertheless, there are few studies of the relationship between structural change and farming systems on one side and environmental impact and multifunctionality of Norwegian agriculture on the other (Dramstad & Sang 2010).

1.2 Farm-level modelling of multifunctionality and environmental impact – Objectives

The objective of this study is to explore and evaluate several aspects of environmental impact and multifunctionality in dairy farming systems. The term "farming system" here refers to a specific arrangement of farming activities established by the farmer in response to the physical, biological and socio-economic environment. In this project the farm unit is used as the boundary for a farming system. Multifunctionality in agricultural systems implies that multiple commodities and non-commodity outputs are jointly produced – the non-commodity outputs can be public goods or positive externalities if there are no functioning markets for these outputs (OECD 2001). Some aspects of multifunctionality, e.g. food security and rural development, are best evaluated at larger scales than the individual farm but the model developed in this project is restricted to describing only processes, outputs and environmental impacts at the farm level. Nevertheless, the model is given an extendible design so that it can be used for scaling up from individual farms to landscapes or regions. It was also an objective in the project that the model should be able to integrate ideas from different disciplines and that it should be possible to use the model to study the expected effects of policy change on the environmental impact of agriculture. This paper gives an outline of the conceptual approach and the basic structure of the model. The model is still under development but some preliminary results are presented and plans for further development of the model are discussed.

2. Modelling approach

2.1 Criteria for evaluating and comparing farming systems

The development of the model started with indentifying a set of criteria to evaluate and compare farming systems. For the farmer, net income is an important criterion for decisions on farm management. Nevertheless, several criteria have to be taken into account to understand the decisions taken by farmers. In a longer perspective, the farmer's income also depends on the production of public goods and services as a proportion of the farmers income comes from economic subsidies and agri-environmental schemes. The development of farming systems with low environmental impact and positive effects on landscape and biodiversity are essential to sustain the level of subsidies and agri-environmental schemes in Norway within international trade-agreements (Norwegian Ministry of Agriculture and Food 2011).

The model includes some key criteria to estimate the environmental impact of the farming systems: nitrogen loss by leaching, emission of greenhouse gasses (GHG), carbon sequestration in soil and the impact of agricultural management on biodiversity in permanent grasslands. Loss of nitrogen by leaching is estimated in a relatively simple model. There are other more advanced models of nitrogen loss by leaching (e.g. Skaggs 1990) but these models require more detailed soil data than what is available in this project. Emission of the greenhouse gasses methane and nitrous oxide, and ammonia from livestock and plant-soil system are estimated using an accounting approach that builds on the IPCC standards. Some adaptions are included to better describe Norwegian conditions. For livestock, N excretion per animal is calculated based on production intensity. Methane emissions are estimated from gross energy intake and a methane conversion rate, depending on livestock category, milk yield of dairy cows and feeding plan as described by Volden and Nes (2010). Emissions from livestock depend on technical solutions for housing and manure handling, and the grazing period. Emissions from the plant-soil system depend on sward and crop type, use of fertilizer and other factors such as time between ploughing and reseeding of swards.

2.2 Biodiversity management index

To evaluate the ecological impact of different management options, a biodiversity management index is developed (for a similar approach, see Jouven et al. 2006). So far, the index has only been developed for evaluating grazing in semi-natural or permanent grasslands. These grasslands contain a large proportion of the plant species diversity on most farms with grassland based animal production (Hamre et al. 2010). Today, grazing is the most common management of semi-natural and permanent grasslands in Norway but the intention is to also include mowing in a new version of the model.

The biodiversity management index is related to a set of simple but also fundamental relationships in ecology like the “hump-shaped curve” relationship between plant diversity and productivity and the intermediate disturbance hypothesis (Grime 1972). The biodiversity management index is calculated at the field level and is scaled so that it takes values between 0 and 1. The value 1 indicates that the management is considered to be “optimal” with respect to conservation of biodiversity in this vegetation type.

The biodiversity management index is a function of the level of disturbance and total exogenous nitrogen input to the system. In the model, the level of disturbance depends on the number and duration of grazing periods and on the proportion of aboveground biomass harvested. The grazing is in the model described by a set of discrete grazing regimes which defines the number of grazing periods and the duration of each grazing period. Only rather simple grazing regimes have been described so far but the model can easily be extended to include other management regimes if sufficient information on the effect of management on biodiversity is available.

In addition to information on the grazing regime, biomass off-take by livestock and nitrogen input, the model also requires data on vegetation and soil. The index can only be calculated for semi-natural grasslands which are defined as grasslands where the vegetation is a result of long-term agricultural use but the species composition is not dominated by sown species or totally altered by ploughing or application of mineral fertilizer. The vegetation is classified based on gradients in fertility, soil moisture and soil organic matter – each gradient described by a single variable. The description of the vegetation is adapted from the new system for classification of nature types in Norway (Halvorsen et al. 2009). The vegetation and soil type influence the functional relationship between management and the biodiversity management index, i.e. different functions are used depending on vegetation and soil type. The purpose of the index is not to predict biodiversity at the field level but rather to indicate the expected impact on biodiversity caused by a change in either nitrogen input or disturbance. This is an important distinction. The biodiversity and community dynamics of permanent grasslands are influenced by a number of factors other than the agricultural management, e.g. the configuration of the surrounding landscape and the regional species pool (Gaujour et al. 2012).

2.3 Basic model structure

The model is built in the Python programming language (version 3.1). The main structures in the model are the livestock module and the plant-soil system module. In the livestock module, milk quota and either milk yield or number of dairy cows are fixed input parameters. In addition, it is necessary to set a minimum and maximum for the proportion of concentrates in the diet for each category of livestock. The livestock module determines the requirements for concentrates and stored and grazed forage. These requirements are important input to the plant-soil module and determine e.g. the quantity of mineral fertilizer used for the different fields.

The estimated farm income in the model includes both incomes from commodities sold from the farm and from subsidies. The subsidies also include agri-environmental schemes given that the farming system or the management satisfies the requirements of the specific scheme. Production costs include fixed and variable costs except labour costs and depreciation of farm buildings. For farm machinery the costs were calculated per produced unit, e.g. machinery costs per kg dry matter silage, based on empirical data from the Norwegian Agricultural Economics Research Institute. Fencing costs per hectare pasture and veterinary costs per animal were calculated using the same approach.

By using a script to generate input to the model, it is possible to step through all combinations of key variables which define the farming system (all key variables are viewed as discrete variables for this purpose). This generates a set of farming systems and the model is then used to calculate the performance of these systems with respect to different criteria for multifunctionality. In this process some farming systems will be sorted out as they do not satisfy specific requirements, e.g. there is not enough pasture available for the livestock. In a final step, it is possible to compare a large number of farming systems created by this routine. It is also possible to specify farming systems “by hand” (see the example in the next section).

3. Results and discussion

3.1. Examples of model output

To illustrate the use of the model, I will provide an example in which three different farming systems are applied on the same farm unit (Table 1). The example is based on an existing dairy farm in the Trøndelag region. The milk quota is the same for all farming systems but the number of dairy cows and thus also the yield per cow differs among the systems. The “High” system has a yield per dairy cow of 7500 kg year-1 (energy corrected milk). The other farming systems both have a yield per dairy cow of 6000 kg year-1. The “Medium” system has the same area of agricultural land available as the “High” system. The “Medium Plus” system has the same yield as the “Medium” system but 6 ha of agricultural land more compared to the other systems. In Norway farmers often have to decide if they want to rent land from other farms which no longer are managed as independent farm units (Dramstad & Sang 2010). There are some variations in the way heifers are reared because of variation in the availability of roughage and pasture. Bulls have the same feeding plan and are slaughtered after eighteen months in all farming systems.

Table 1. The three farming systems “High”, “Medium” and “Medium Plus” are outlined in the table.

	Farming system		
	"High"	"Medium"	"Medium Plus"
Farm land, ha	27	27	33
Cultivated ley, ha	14	14	16
Permanent pasture, ha	13	13	17
Milk quota, kg milk	150 000	150 000	150 000
Dairy cows	19	24	24
Yield per cow, kg milk	7 500	6 000	6 000
Forage requirement, FEm × 1000 †	164	184	184

† FEm = Feed units milk (Ekern 1991), calculated energy content in feed, 1 FEm=6.9 MJ NE_l, where NE_l is the net energy for lactation.

In this paper, I present three of the indicators used to evaluate and compare the farming systems (Figure 1). It is important to stress that these results are preliminary and provided only to illustrate the use of the model! The biodiversity management index is on a relative scale and has only been calculated for semi-natural and permanent grasslands. Area has been used as weights when aggregating the index at the farm level. The total methane emissions are calculated for farm activities only, i.e. emissions from the production of machinery, mineral fertilizer etc. are not included.

3.2 Economic results and environmental impacts

The preliminary results indicate that adjusting the livestock system to match the production of roughage and pasture is important both for the economic result and the environmental impact. The livestock system can be adjusted to the farms plant production either by reducing the number of livestock or lowering the production intensity, e.g. milk yield per cow. In the example, the “High” and “Medium Plus” farming systems gave approximately equal net income. The “Medium” system with a larger herd but no extra land had the lowest net income of the three systems considered in the example. Both the farming systems with medium yield had higher methane emissions than the high yield system in the example. The results for nitrous oxides emissions indicate a similar ratio between emissions in the high and medium yield systems. However, the differences in on-farm GHG emissions between the high and medium yield farming systems in the example are relatively small compared to the total emissions. Similar conclusions have been made in studies comparing GHG emissions in organic farming systems with medium yield and conventional systems with high yield (Kristensen et al. 2011; Van der Werf et al. 2009).

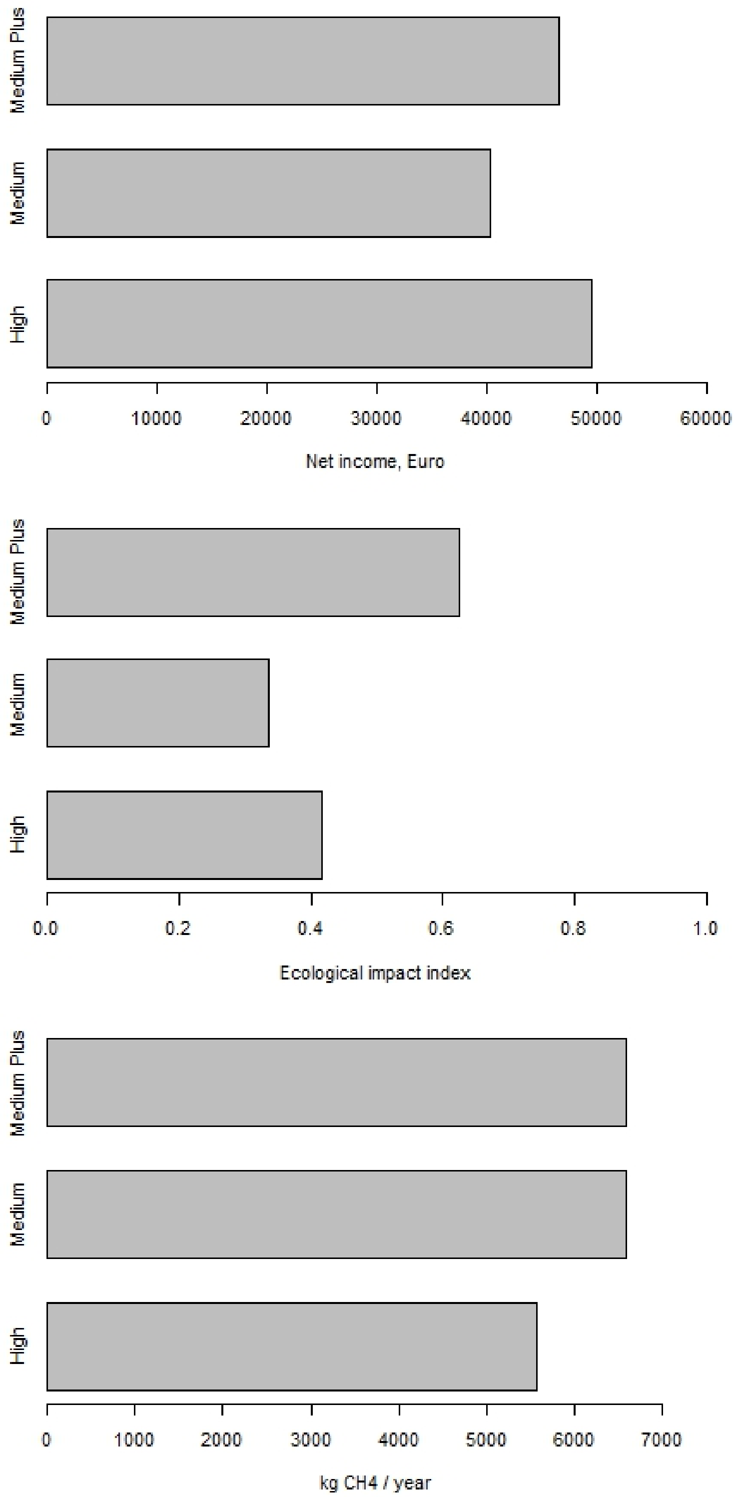

Figure 1. Preliminary results for three of the criteria used to compare and evaluate farming systems in the project. The three farming systems "High", "Medium " and "Medium Plus" are compared in the figure.

When it comes to biodiversity of semi-natural and permanent grasslands, the “Medium Plus” farming system had the most favourable management. The grazing intensity in this system was more optimal for promoting species and plant communities characteristic to semi-natural habitats. The larger area of land available reduced the motivation for using mineral fertilizer on pastures to improve pasture forage production. The farming system with medium yield but no additional land gave a lower value of the biodiversity management index than the farming system with higher yield. This illustrate that extensification of the animal production system by distributing the same milk production on more cows with lower yield in some situations can create a need for intensification of the plant production on the farm. Higher demand for roughage and pasture can entail more intensive utilization semi-natural and permanent pastures and this can in turn have negative effects on biodiversity. High grazing pressure is not necessarily negative if there is variation in grazing pressure and sward height within the pasture (Pehrson 2001). For many permanent pastures the grazing pressure is probably lower than the optimum if the objective is to promote the diversity of plant species and communities characteristic to light-open and low productive grasslands.

Farms with small areas for roughage production relative to the milk quota will have the highest profitability with high yielding dairy cows. For farms with larger areas with land suitable for roughage production, there are more options. On these farms, extensification of both the animal and plant production systems can reduce costs and also provide possibilities for increased income from agri-environmental schemes. With more land available for roughage and pasture production the farmer often have more possibilities to have a management of grasslands which promotes biodiversity and fits the requirements in agri-environmental schemes. (It should be noted here that many of the “green” agricultural subsidies in Norway are not very specific but rather try to increase the number of grazing animals and avoid abandonment of agricultural land. Land abandonment is considered as one of the most important treats for biodiversity in Norway [Nybø et al. 2011]). The optimal system for forage production and intensity in management of grasslands also depend on the potential and economy in using agricultural land for other crops, for example there is for some farmers a trade-off between using land for grass production or for arable crops (Flaten 2001). The results from the model indicate that extensification of the animal production system often is entailed by higher emissions of greenhouse gasses. Extensification of the plant production system may have the opposite effect but there are still a need for more knowledge on management of grassland production systems and GHG emissions.

3.3. Further development of the model

The model is still under development and extensive testing of the model is needed before we can present final results and conclusions. The biodiversity management index is one of the elements that needs more work. The index is presented on a relative scale (without units) but it is still important to ensure that the impact of different variables is expressed at the same scale. For example, it is necessary to ensure that the difference between two grazing regimes is expressed at the same scale as the difference between levels of N supply.

Several of the processes and functions related to the multifunctionality of farming can best be studied at the landscape or regional scale. For example, the landscape connectivity with respect to ecological processes can best be studied when several farms are considered together. The same is also the case for socio-economic processes as land tenancy and cooperation between farmers. We are currently working on funding a new project to scale up to the landscape and regional scale. The intention is to build an agent-based model using a version of the model presented here to describe the behaviour of individual agents. Other ideas for further development of the model is to explore the potential for integrating this model with multi-criteria analysis or LCA analysis (see e.g. Davis et al 2009).

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5. References

Almås, R. & Brobakk, J. (2012). Norwegian Dairy Industry: A Case of Super-Regulated Co-Operativism. –In: Rethinking Agricultural Policy Regimes: Food Security, Climate Change and the Future Resilience of Global Agriculture. Research in Rural Sociology and Development, Volume 18. Almås & Campbell, H (eds) Emerald Group Publishing Limited, Bradford, UK. Research in Rural Sociology and Development, Volume 18: 169 - 189

Cooke, I.R., Queenborough, S.A., Mattison, E.H.A. et al. (2009) Integrating socio-economics and ecology: a taxonomy of quantitative methods and a review of their use in agro-ecology. *Journal of Applied Ecology* 46: 269-277.

Davis, C., Nikolic, I. and Dijkema, G.P.J. (2009). Integration of Life Cycle Assessment into agent-based modeling. Toward informed decisions on evolving infrastructure systems. *Journal of Industrial Ecology* 13: 306-325

Dramstad, W.E. & Sang, N. (2010). Tenancy in Norwegian agriculture. *Land Use Policy* 27: 946-956.

Ekern, A. (1991). Nytt system for energivurdering av fôr til drøvtyggere. [A new system of energy evaluation of food for ruminants, in Norwegian] *Norsk Landbruksforskning* 5: 273–277.

Emanuelsson, E. (2009). The rural landscapes of Europe - How man has shaped European nature. Forskningsrådet Formas, Stockholm.

Gaujour, E., Amiaud, B., Mignolet, C. & Plantureux, S. (2012). Factors and processes affecting plant biodiversity in permanent grasslands. A review. *Agronomy for Sustainable Development* 32: 133-160.

Grime J.P. (1973). Competitive exclusion in herbaceous vegetation. *Nature* 242: 344–347.

Halvorsen, R., Andersen, T., Blom, H.H. *et al.* (2009). Naturtyper i Norge (NiN) version 1.0.0. Artsdatabanken, Trondheim. Available at www.naturtyper.artsdatabanken.no

Hamre, L.N., Halvorsen, R., Edvardsen, A. and Rydgren, K. (2010). Plant species richness, composition and habitat specificity in a Norwegian agricultural landscape. *Agriculture, Ecosystems & Environment* 138: 189–196

Jouven, M., Carre`re, P. & Baumont, R. (2006). Model predicting the dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description. *Grass and Forage Science* 61: 112-124.

Kristensen, T., Mogensen, L., Knudsen, M.T., & Hermansen, J.E. (2011). Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. *Livestock Science* 140: 136-148

Mandryk, M., Reidsma, P. and van Ittersum, M.K. (2012). Scenarios of long-term farm structural change for application in climate change impact assessment. *Landscape Ecology* 27: 509-527

Norwegian Ministry of Agriculture and Food (2011). Landbruks- og matpolitikken. Velkommen til bords. Melding til Stortinget 9 (2011-2012) [In Norwegian]. Norwegian Ministry of Agriculture and Food, Oslo.

Nybø, S., Certain, G. & Skarpaas, O. (2011). The Norwegian Nature Index 2010. DN Report 2011-1. Norwegian Directorate for Nature Management, Trondheim.

Pehrson, I. (2001). Bete och betesdjur. Jordbruksverket, Falköping, Sweden.

Skaggs, R.W. (1990) *DRAINMOD User's Manual.* North Carolina State University, Raleigh (http://www.bae.ncsu.edu/soil_water/drainmod/)

Statistics Norway (2012) Tables with agricultural statistics for Norway, available at http://www.ssb.no/jordbruk_en/

Stoate, C., Baldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L. & Ramwell, C. (2009). Ecological impacts of early 21st century agricultural change in Europe – A review. *Journal of Environmental Management* 91: 22-46.

Volden, H. & Nes, S.K. (2010). Methane emissions from enteric fermentation in Norwegian's cattle and sheep population. Method description. In: T. Sandmo (ed) The Norwegian Emission Inventory 2010. Documentation of methodologies for estimating emission of greenhouse gases and long-rage transbounary air pollutants. Statistics Norway, Oslo, pp 220-230 (appendix H)