GHG abatement welfare cost curves for Norwegian agriculture

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Abstract

Agriculture makes a significant contribution to Norway's emissions of greenhouse gases (GHG). Although the sector accounts for only 0.3 per cent of GDP, it accounts for roughly 9 per cent of total GHG emissions. Norwegian agriculture is dominated by livestock production; ruminants (cattle and sheep) are particularly important. There are opportunities for GHG mitigation under existing technology through changes in agricultural practices. Analytically we derive abatement cost curves for Norway in terms of the change in economic welfare, and on a theoretical basis we examine the impact of various policy objectives on the abatement cost curve. In particular we consider the policy objective of keeping the production of calories at the current level. We use a detailed economic model to assess the impact and welfare implication of a reduction in GHG emissions.

Keywords: greenhouse gas mitigation; economic model; abatement costs

JEL code: C61, Q18, Q54

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1. Introduction

Situated on the northern rim of Europe, Norway has clear disadvantages in agriculture. Not only does it have a cold climate and a short growing season, but also a topography that entails steep and scattered land plots. Only 3 per cent of the total land area is infield agricultural land, and only one third of that land is suitable for food grain production. Consequently, most of Norway's agricultural land can only be utilized by ruminants (beef cows and sheep) that generate relatively high greenhouse gas (GHG) emissions.

Despite the harsh production conditions, Norway is more or less self-sufficient in animal products and close to self-sufficient in feed grains, while the self-sufficiency rate for food grain is normally between 50-75 per cent. Substantial agricultural support, estimated by the OECD as equal to 63 per cent of the production value, is required to keep output at high levels. Although Norwegian agriculture accounts for roughly 0.3% of gross domestic product, it accounts for roughly 9 per cent of the country's total GHG emissions.

Norway has been a strong supporter of initiatives to reduce global GHG emissions. Taking into consideration the relatively high emissions from the country's agricultural sector, it is important to investigate the implications of efforts to reduce these. To this end, a familiar method is to estimate the marginal abatement cost curve (MAC). Most commonly, this is computed as the effect of abatement options on costs at the farm level (e.g., MacLeod et al., 2010). However, this approach can provide an incomplete picture of the benefits and costs of abatement if there are significant implications for economic welfare (Morris et al., 2012).

A welfare-based perspective is particularly appropriate for Norway because as far as agriculture is concerned the country is essentially a closed economy. Changes in production associated with GHG abatement will not only have significant implications for producer costs and economic surplus, but also for consumer surplus and taxpayer costs.

In this paper we discuss the derivation of abatement costs for Norwegian agriculture in terms of the change in economic welfare. This is done under the assumption that we also maintain the current cultivated land area (often expressed as a public good objective in Norway). But even if cultivated land should be kept open and productive, this does not necessarily have to be used in existing ways i.e., the use of set-aside or a land bank is permitted. On a theoretical basis we also examine the impact of a second constraint on the abatement cost curve – to maintain the current self-sufficiency rate for food (often expressed in the form of a production target and emphasised as an objective by policymakers in Norway). We illustrate the implications of this policy objective for the abatement cost curve by assuming that the per capita production of calories should be kept at the current level. When the abatement cost curve is subject to such a constraint related to production, the abatement cost curve changes markedly.

To measure abatement costs and economic welfare we use a partial equilibrium model of the Norwegian agricultural sector that has been adapted for climate policy analysis, see for example Blandford *et al.* (2013) and Blandford *et al.* (2014). In this preliminary paper we present empirical results for the unconstrained abatement cost curve which will provide the point of reference for the policy constrained options.

In the next section we derive the basic principles utilizing a simplified structure. Sections 3-4 outline the empirical model and the results obtained, while Section 5 offers the main conclusions.

2. A simplified exposition of the basis of our analysis

Using simplifying assumptions this section outlines key issues involved in deriving the abatement cost curve for Norwegian agriculture. We consider a small country facing given world market prices. The country we look at follows a policy of self-sufficiency, so agriculture is protected through prohibitive tariffs. For analytical purposes we assume that the sector produces only two commodities: crops and ruminants. Ruminants are an example of a a high emission product (due to emissions of methane), while crops are viewed to be a relatively low emission product. We require that all available land has to be used. And we assume a simple Cobb-Douglas production structure for both commodities.

Crops

Crops are produced on farms which use land (L_C) and an aggregate of other inputs (K_C), hereafter referred to as capital. The Cobb-Douglas function is:

(1) $$Y_C = K_C^{\alpha_C} L_C^{\beta_C} .$$

Farmers can increase production by using more land or by using more capital. The effect on production by using more capital is given by α_C.

As for emissions associated with the production of crops, E_C, we assume that these can be represented by the formula:

(2) $$E_C = \left(\frac{K_C}{L_C}\right)^{\rho_C} Y_C, \qquad \rho_C>0.$$

The rationale for (2) is that the level of emissions depends on chosen production techniques. A technique that is intensive in the use of fertilizer, for example, (which is included in K) pollutes more than a less intensive technique. The parameter ρ_C measures the strength of this effect, which we will refer to as the *intensity effect* in emissions. Secondly, the volume of production matters. We will refer to this as the *production effect*. So for crops, emissions are determined by the intensity of the use of K and also by the scale of production. The relationship (2) is exceedingly simple, but it captures several key factors. In particular, if more land is used in the production of crops, Y_C will increase and so will emissions. In contrast, by holding K_C constant, production will become less capital intensive and emissions per unit of output will decrease. These effects can be clarified by differentiating (2) with respect to L_C:

(3) $$\frac{dE_C/E_C}{dL_C/L_C} = \beta_C - \rho_C$$

The percentage increase in emissions from a one percent increase in land use equals the production effect, which follows from the distribution parameter for land in the Cobb-Douglas production function (β_C), minus the intensity effect, which equals the parameter ρ_C in (1). In our analysis we assume that the production effect exceeds the substitution effect, i.e.

$$\beta_C - \rho_C > 0.$$

Ruminant farm

In the case ruminant farming (R), the Cobb-Douglas production function is written as:

(4) $$Y_R = (K_R)^{\alpha_R}(L_R)^{\beta_R}.$$

K_R is an aggregate of other inputs (labour, corn, fertilizer, real capital, etc.), again referred to as capital. On a ruminant farm land, $L_{R,}$ is used to grow grass, which is then used as feed. As for emissions, methane is the most important source. The formula is given as

(5) $$E_R = \gamma_R \left(\frac{K_R}{L_R}\right)^{\rho_R} Y_R, \qquad \rho_R < 0.$$

Here, ρ_R measure the substitution effect. γ_R is a parameter that is set such that emissions in ruminant farming are larger than for crops. If more land is used, keeping capital constant, the intake of grass increases and so will production and emissions (production effect). But the substitution parameter ρ_R is in this case negative. Since capital is constant, the feed composition changes toward grass, which means more emissions. Therefore, in the case of ruminants farming the substitution effect reinforces the production effect.

Aggregate relationships

For the country we require that all land will be used, i.e.

(6) $$L_G + L_C = \overline{L}\,,$$

where $\overline{L}$ is the total amount of agricultural land available.

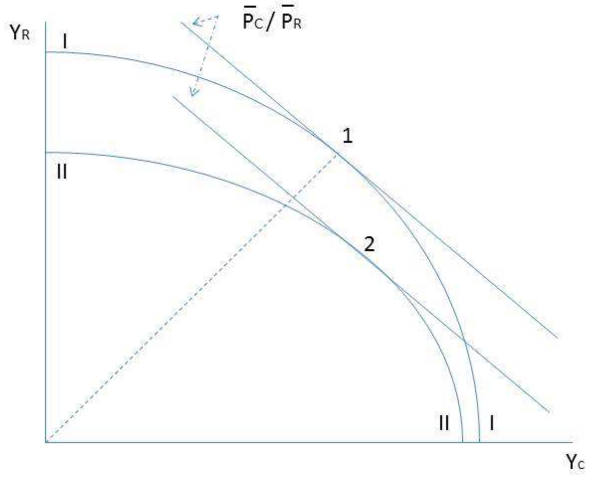
We also keep track of the calorie content from consuming Norwegian products. Denote κ_C as the per kilo calorie content of crops, and κ_R as the corresponding parameter for meat derived from ruminants. The population's total intake of calories from consuming food, *F,* based on Norwegian agriculture commodities is:

(7) $$F{=}\kappa_C Y_C + \kappa_R Y_R$$

Illustrations of model solutions

From the production side, the aggregate model consists of the equations (1), (4) and (6). We assume given input prices for capital connected to the production of crops and. Based on these assumptions we can trace out the production possibility frontier marked as I-I in Figure 1. On the vertical and horizontal axis we have quantities of ruminants and crops respectively. The market solution is marked as 1, meaning that the relative price between ruminants and crops, $\overline{P}_C/\overline{P}_R$, is set such that point 1 is reached. Underlying the market prices $\overline{P}_C$ and $\overline{P}_R$ are production subsidies, so these prices reflect national preferences. Point 1 will be referred to as the base solution.

Figure 1: The production possibility frontier of the agricultural sector



Assume now that the sector cannot exceed an maximum level of emissions denoted by $\bar{E}$:

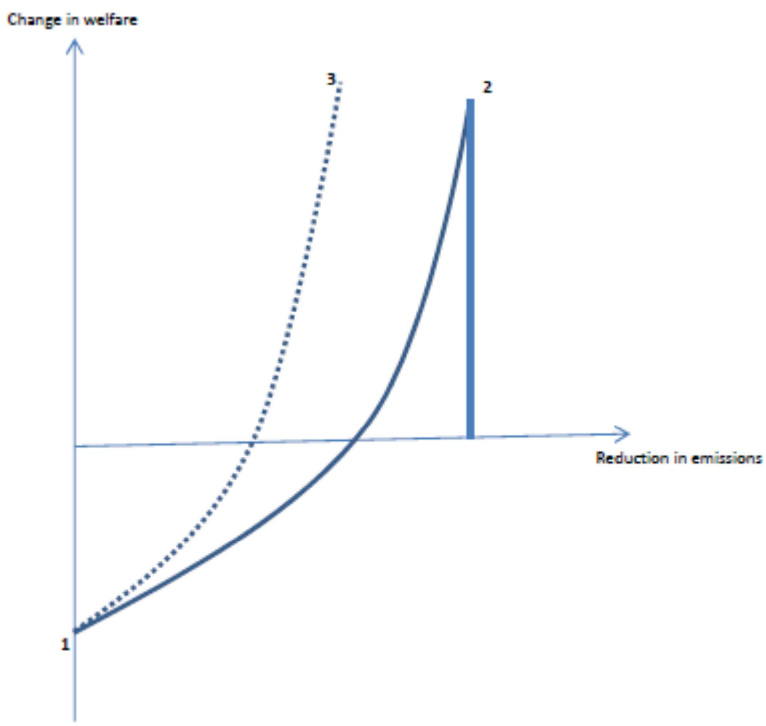
$$E_C + E_R \leq \bar{E}.$$

This maximum may be determined to meet a domestic objective for greenhouse gas mitigation or through international agreement. This requires that that emissions have to be decreased compared to the level under the base solution. Taking into account the pollution formulas (2) and (5), the revised production possibility frontier is marked as II-II. The shape of this curve will reflect two different types of substitution. First, we have substitution within the separate product lines. Requirements to emit less carbon, for example through a carbon tax, motivate the use of less polluting production techniques. This applies to both product lines. Second substitution will also take place between product lines. Since ruminants are more polluting than crops, economic efficiency counts in favour of the latter. The new solution is marked as point 2 in Figure 1. Since point 2 lies below the straight line going through the origin, the reduction in ruminant production is larger than that for crops. Notice that we have not changed relative prices of the two outputs.[1]

[1] In the model we use in sections 3-4, welfare is measured as the sum of consumer and producer surplus. A detailed outline of the procedure behind this is given in Blandford *et al*. (2014).

In Figure 2 we have drawn in the abatement cost curve underlying the experiments in Figure 1. In the literature a standard abatement cost curve is drawn on a diagram in which the horizontal axis denotes reduction in emissions from a range of abatement options, while the vertical axis measure marginal costs connected to these options. Instead of marginal costs we use the change in welfare, i.e. the vertical axis measure the change in welfare as a result of reductions in emissions. In Figure 2 point 1 refers to the base solution, while point 2 marks the assumed maximum for emissions. The line drawn between point 1 and 2 is the result of experiments using continuous reductions in emissions. Observe that most of the abatement cost curve lies below the horizontal axis. That means that from an economic point of view it will be welfare enhancing to reduce activity in Norwegian agriculture, and simultaneously generating lower GHG emissions. In Norway the abandonment of the use of high organic soils for beef and sheep production will typically be at the low end of the abatement cost curve (yielding the highest welfare gain). These activities are not only emissions intensive, but also costly and land extensive. In contrast, vegetable production on the most productive land in south-east part of Norway, which generates low emissions, is likely to be at the upper end of the abatement cost curve.

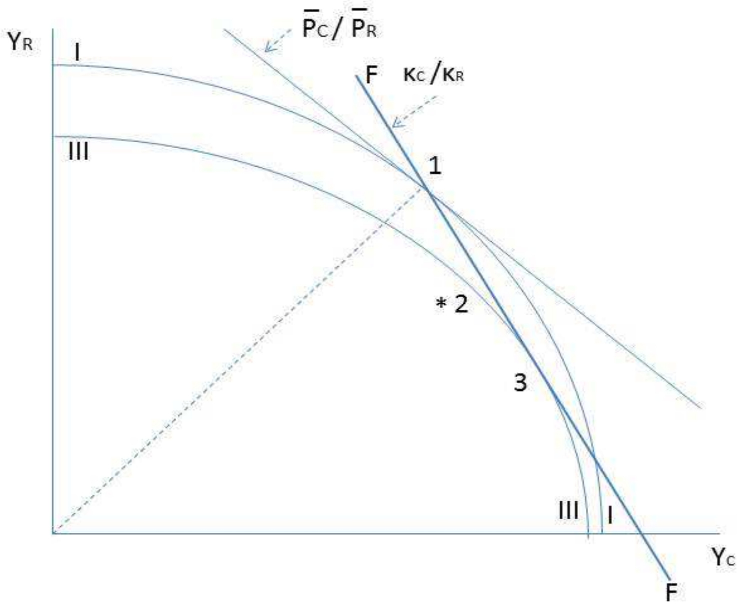
Figure 2: Abatement cost curves



Assume now that the policy of the authorities is that the Norwegian agricultural sector shall produce a certain amount of calories, for example the same amount as in the base solution, F^1. In Figure 3, the line F-F marks the selection of diets based on ruminants and crops that provide the required amount of calories. Production possibility frontiers I-I, as well as point 1 and 2 are the same as in Figure 1. We see here that it will be impossible for the authorities to meet both the calorie target, F^1, and the required reduction in emissions. The largest reduction in emissions that can be obtained is $\bar{\bar{E}}$, upon which the production possibility curve III-III in Figure 3 is based.

The dotted line in Figure 2 is the abatement cost curve based on the assumption that the calorie requirement must be met. We see that the abatement cost curve shifts upwards, and, compared to the unrestricted curve, becomes steeper with increasing emissions reductions. For example, at the lower end of the curve, the calorie requirement can be met with both lower costs and emissions by switching from ruminants to vegetable products and white meat. However, when land suitable for grain and vegetables is exhausted, remaining calories have to come from ruminants that can utilize grassland. Consequently, the abatement cost curve becomes steeper.

Figure 3: The restricted production possibility frontier of the agricultural sector



3. The empirical model and the representation of GHG emissions

Our sector model (Jordmod) has been used previously to address a number of policy issues (Brunstad *et al*., 1999 and 2005, Blandford *et al*. 2010). An overview and a technical description of Jordmod is given in Blandford *et al*. (2014). We provide a brief overview of the model, with an emphasis on how it has been adapted to reflect GHG emissions from Norwegian agriculture.

Functions and coefficients have been attached to activities and production factors in Jordmod to reflect GHG emissions, based on the Intergovernmental Panel Climate Change (IPCC) methodology, adapted to Norwegian conditions and practices.[2] Details are given in Gaasland and Glomsrød (2010). For milk cows, emissions from enteric fermentation are represented as a function of the amount and mixture of feed, while for all other animals they are reflected by an animal-specific constant parameter per head. The amount of manure, which leads to emissions of methane and nitrous oxide from manure management and nitrous oxide from the use of manure as fertilizer, is modelled as a function of fodder intake for milk cows and as an animal-specific constant for other animals. For manure management, animal-specific emission parameters depend on the manure management system. Constant parameters per unit of nitrogen, which differ between the use of manure and synthetic fertilizer, represent emission of nitrous oxide from the use of fertilizer. Emissions from land use relate to carbon dioxide that is released from tilled mineral soil (estimated to be 1,000 kg per hectare per year).

GHG emissions estimated by the model, distributed by sources and gases for the base year of 2004, are given in Table 1. Norwegian agricultural production and agricultural policy have been relatively stable in recent years, so the base year is representative. Methane from enteric fermentation accounted for 45 per cent of total emissions in 2004, while manure management contributed 27 per cent. Use of synthetic fertilizer and carbon loss from soil each account for about 10 per cent. Total emissions estimated by the model for 2004 are 4,131 thousand tons. The figure actually reported to the United Nations for 2004 (National Inventory Report 2013 – Norway) was 4,311 thousand tons.[3]

[2] Values are for 100-year time horizon global warming potential relative to CO_2 from the IPCC second assessment report (SAR, 1995). These values are those currently used by the Norwegian authorities in preparing GHG inventory reports for the United Nations. Although values have been revised in the fourth assessment report (AR4, 2007) we chose not to use these in order to maintain consistency with Norway's reporting procedures. Changing the coefficients would affect our numerical results but would not affect the qualitative conclusions reached.

[3] http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3734.php

Table 1. GHG emissions in CO_2 equivalent (1,000 tons) distributed by sources and gases (2004). Global warming potential (GWP) values: CH_4 = 21, N_20 = 310, and CO_2 = 1.

Source	**Methane** (CH_4)	**Nitrous oxide** (N_2O)	**Carbon dioxide** (CO_2)	**Total**	*(share)*
Enteric fermentation	1,843			1,843	41 %
Manure management	689	420		1,109	24 %
Fertilizer, manure		231		231	5 %
Fertilizer, synthetic		504		504	11 %
Nitrogen runoff		69		69	2 %
Land, net carbon loss			375	375	8 %
Fossil fuel			411	411	9 %
Total	2,532	1,224	786	4,542	
(share)	56 %	27 %	17 %		

Table 2 presents estimates of emissions for representative farm types in the model. These illuminate the potential for mitigation by means of substitution through changes in the structure of output in Norwegian agriculture. It can be seen that emissions generated in the production of beef and sheep/lamb meat are by far the highest, both per kg and in terms of output valued at world market prices. White meat and eggs are in the middle range per kg of product, and at the low end in terms of the value of output. Emissions relating to milk production are relatively low, especially per kg of milk. They are by far the lowest for vegetables, represented by potatoes.

Mitigation options and mechanisms included in the model, e.g. as a response to a carbon tax, are as follows: 1) activities with high emissions (e.g., ruminants) may decline to the benefit of those with lower emissions (e.g., monogastric animals, grain, and vegetables); 2) the intensity of fertilizer use may decrease (i.e., land may be substituted for fertilizer); 3) the intensity of feeding of dairy cows may change (the use of more grain and protein feed); and 4) a switch between tilled land (regularly ploughed), grassland and pasture may take place.

Table 2. Estimated GHG emissions (CO_2 equivalents in kg) for representative farm types – including emissions related to purchased feed[a]

Farm types	Per kg	Per NOK[b]	Per ha
Extensive beef	27.28	2.10	3,829
Sheep	19.69	0.98	3,982
Pigs	4.42	0.37	3,948
Poultry	3.00	0.33	4,278
Eggs	1.85	0.19	2,194
Combined milk and beef	0.66[c]	0.60	3,852
Grain	0.38	0.50	1,661
Potatoes	0.12	0.05	1,581

[a] CO_2 emission estimated at 0.41 kg per unit of purchased grain, based on an average barley yield of 3,670 feed units per ha and 84 kg N fertilizer per ha.
[b] Emission is divided by production at the farm valued at world market prices. NOK = Norwegian krone. The exchange rate is €1=8.3 NOK.
[c] Per kg of milk. Emissions from beef production are deducted (assuming 20 kg CO_2 equivalent per kg of beef).

4. Empirical analysis

We investigate the welfare cost of reducing GHG emissions relating to the use of land in agricultural production. Our analysis takes the perspective of a small country with a comparative disadvantage in agricultural production, but whose political objective, nevertheless, is to keep agricultural activity as high as possible within an assumed constraint on GHG emissions.

The point of departure is existing policy, as reflected in the model, for the base year of 2004. Since Norwegian agricultural markets are highly distorted by subsidies and import tariffs, the solutions that result from our analysis are not economically efficient, but rather reflect an adjustment to existing agricultural policies. The closed economy character of the Norwegian agricultural sector due to high tariffs implies that import costs are far above domestic market prices, and this eliminates the possibility of carbon leakage in our analysis (i.e., export of GHG emissions). Consequently, depending on the prevailing supply and demand conditions, a carbon tax will be reflected in domestic consumer and producer prices for agricultural products.

We assume that GHG emissions relating to use of land in agricultural production must be reduced by 30 per cent, which can be interpreted as a sector specific target for emission reduction. A reduction of this magnitude was proposed by Norway in the run-up to the climate change conference in Copenhagen in 2009. In order to provide incentives to reduce emissions by changing farm level practices or to shift from high to low emission outputs, we introduce a Pigovian tax of NOK 300 per ton of GHG emissions (measured in CO_2 equivalent). Based on the change in practices and production composition that follows from imposing the tax, we then scale the aggregate level of production (i.e., the policy objective variable) up or down to meet the 30 per cent emission target.

A GHG tax has differential impacts on profitability for Norwegian farming systems. As shown in Table 2, ruminants like cattle and sheep cause high emissions, both relative to output and the use of farm land, while emissions are moderate for milk and relatively low for white meat, eggs, grain and vegetables. We have also seen that only a minor part of differences in emissions can be mitigated by farm level adaptation, e.g., by changing existing practices in livestock feeding or the use of fertilizer. Consequently, in order to achieve substantial abatement of emissions while achieving the objective of maintaining aggregate food production, sector level adjustments will be necessary in the form of a switch in the structure of production from high to low emission products. The sectoral results derived from Jordmod in Table 3 illustrate this adjustment. We first compute the base solution. For this solution every number is normalized, i.e. set equal to 100. The base solution was marked as point 1 in Figures 1-3.

Table 3. Sector level mitigation – model simulations

	Base solution	Carbon tax
Production	100	77
Cow milk	100	82
Other ruminants	100	66
White meat and eggs	100	83
Grains and potatoes	100	74
Farm land usage	100	74
Production intensity		
Nitrogen per ha	100	95
Yield per dairy cow	100	119
Share of grass fodder	100	96
Emissions from agricultural activity (CO_2 equivalent)	**100**	**70**
Per NOK produced (at world market prices)	100	91
Per hectare	100	96
Agricultural support	100	74
Economic welfare	100	119

Table 3 shows the main results compared to the base solution. Column 2 shows that a 23 per cent reduction in agricultural production is required to achieve the 30 per cent GHG abatement target. Adaptation, both at farm and sector level, explains why production declines less than emissions. At the sector level ruminants like beef and sheep suffer a larger reduction in output than white meat and milk. The reduction for grain is mainly a result of lower agricultural activity that reduces the demand for grain-based feed. While the 30 per cent emission abatement involves costs in terms of production forgone, gains are generated from lower taxpayer expenditures on agricultural support and there is a resulting 19 % increase in economic welfare. This welfare result is more or less a consequence of lower support-driven agricultural production. This means that the results from the experiment conform to the representation of the abatement cost curves in Figure 2.

5. Conclusion

In this paper we have examined GHG emission abatement costs in terms of change in welfare. The point of departure is the current situation where the Norwegian agricultural sector is highly protected and a key policy objective is to keep production as high as possible. When a carbon tax is introduced more emission friendly production techniques will be used. Production will also be somewhat reduced, since it becomes more costly. That means that from an economic point of view it will be welfare enhancing to reduce activity in Norwegian agriculture, and simultaneously generate lower emissions. The abandonment of the use of high organic soil used in beef and sheep production will typically be at the low end of the abatement cost curve (yielding the highest welfare gain). These activities are not only emissions intensive, but also costly and land extensive. In contrast, vegetable production on the most productive land in south-east part of Norway, which generates low emissions, can be found at the upper end of the abatement cost curve.

Even through our analysis is confined to the particular circumstances of Norway it has implications for other northern European countries whose agriculture is dominated by ruminants. In addition, the results are supportive of arguments made by others on the need for changes in input mix and a shift to lower emitting sources of protein if the food needs of growing global population are to be satisfied, while at the same time constraining the contribution of agricultural activity to the accumulation of greenhouse gases in the atmosphere.

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