Policy options for GHG mitigation under autarky: a conceptual and empirical analysis for Norway

David Blandford*
The Pennsylvania State University, University Park, PA, U.S.A.
Ivar Gaasland
Institute for Research in Economics and Business Administration,
Bergen, Norway
Katharina Hassapoyannes
Greece
Erling Vårdal
University of Bergen, Norway

Contributed Paper prepared for presentation at the 89th Annual Conference of the Agricultural Economics Society, University of Warwick, England

13 - 15 April 2015

Abstract

Agriculture makes a significant contribution to Norway's emissions of greenhouse gases (GHG). Although agriculture accounts for only 0.3 per cent of GDP, it accounts for roughly 8 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. We derive an abatement cost curve for Norway in terms of the change in economic welfare. We require Norway to be self-sufficient in agricultural products; i.e. that domestic production of calories shall be kept at the current level. We use a detailed economic model to assess the impact and welfare implication of a reduction in GHG emissions. We find that a large part of the abatement cost curve is negative due to distortions created by domestic support policies. The practical consequence is that emissions reduction requires that production of grain-based products be increased at the expense of ruminant-based products.

Keywords: greenhouse gas mitigation; economic model; abatement costs
JEL code: C61, Q18, Q54

* Corresponding author; Address: Department of Agricultural Economics, Sociology and Education, Pennsylvania State University, University Park, PA, 16802. U.S.A. Phone: +1 814 863 8648. E-mail: dblandford@psu.edu

1. Introduction

Agriculture, which currently accounts for 0.3 per cent of Norway's GDP and 2.2 per cent of its domestic employment, is among the most heavily protected in the world (NILF, 2007). The OECD's Producer Support Estimate (PSE) for Norway, at almost 53 per cent in 2013, is among the highest for the Organization's member countries (OECD, 2014). Although agriculture accounts for a very small share of Norway's gross domestic product (GDP), it is estimated to contribute around 8% of Norway's emissions of greenhouse gases (GHGs). Methane produced by farm animals, particularly cattle and sheep, which are the backbone of farming in the country, make up roughly 80% of total GHG emissions from agriculture. The production of milk and beef alone is estimated to account for over 60%.

Norway has a complex system of farm subsidies involving deficiency payments, structural income support, acreage and headage payments, and a range of indirect supports. The support system is buttressed by substantial import protection, which severely limits market access. Border protection is extremely high (WTO, 2001). The applied average tariff on all agricultural products under Chapter 2 of the harmonized system was 38 per cent in 2004 (WTO, 2004). However, 44 per cent of the bound most-favoured nation (MFN) tariffs are in the range of 100-400 per cent. In addition, Norway has the highest number of Tariff-Rate Quotas (TRQs) of any WTO member country: 232 out of a WTO total of 1,425. In-quota tariff rates also generally exceed 100 per cent. In effect, Norwegian agriculture operates under autarkic conditions.

Norway has been a strong supporter of initiatives to reduce global GHG emissions, for example, by proposing a 30 per cent reduction from base period levels in the run-up to the UN climate change conference in Copenhagen in November 2009. Unlike many other countries, sectors that would otherwise be expected to play a major part in the reduction of emissions, such as power utilities, are minor players in Norway, since much of the country's domestic energy supply comes from hydro-electricity. If Norway is to meet a significant target for GHG reductions as a result of an international climate change agreement, it seems clear that agriculture will have to play its part. 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 (MACC). Most commonly, this is computed as the effect of abatement options on costs at the farm level (e.g., MacLeod et al., 2010), i.e., in terms of private costs for farmers. However, this approach can provide an incomplete picture of the overall benefits and costs of abatement if there are significant implications for national 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 derive analytically a MACC for agriculture in Norway in terms of the change in economic welfare. We take as given that the current self-sufficiency rate for food (often expressed in the form of a production target) must be maintained, since this is a key aim for Norwegian policymakers.

We begin by using an expansion of the emissions identity to discuss policy options for GHG reduction in the autarkic case. In so doing, we highlight the importance of emissions intensity for policy effectiveness. With reference to the Norwegian case the emission intensity is high, mainly because of the product mix. Emissions can be brought down substantially by producing more meat based on monogastric animals at the expense of meat based on ruminants. 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 the next section we discuss 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. Theoretical analysis

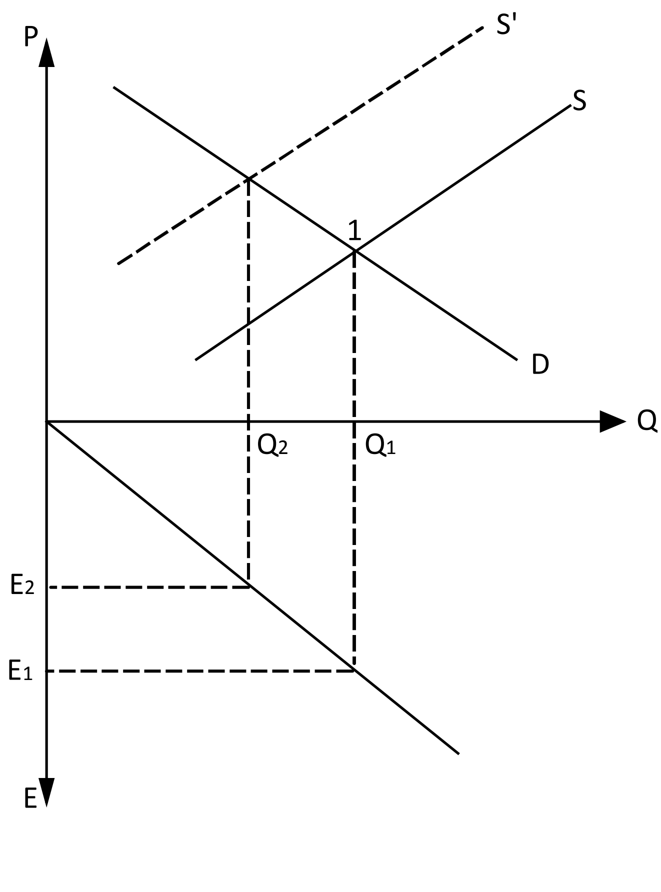
Options for reducing GHG emissions from agriculture, *E*, can be highlighted by examining the following identity:

$$E = \left(\frac{E}{Q}\right) Q,$$

where *Q* is a composite of agricultural products.

Emissions can be reduced either by reducing activity (*Q*), or by lower emissions intensity, i.e. reducing (*Q/E*). This last component depends on possibilities for using emission friendly production techniques, measured by the emission elasticity, ${dlnE}/{dlnQ}$. In Figure 1 we illustrate this relationship for an emissions elasticity of one. The initial equilibrium is marked 1.

Figure 1: Impact of a production tax on emission



The production of Q^1 has a corresponding emission of E^1. Emissions can be decreased from E^1 to E^2 through the imposition of a production tax. The way this tax on production can be implemented can vary from the use of an emissions tax, a tax on the carbon content of products, or by placing a cap on emissions by industries and allowing the trading of emissions permits. Regardless of which method is adopted the tax shifts the supply curve from *S* to *S'*. The tax necessary to promote this decline in emissions depends on elasticities of demand and supply. Based on Gardener (1987, p. 30-32), we have computed the following effects. This indicates that the higher the supply and demand elasticities, the lower the tax required to promote a given decline in emissions.

Table 1: Percentage change in emissions for a 1 percent production tax (emissions elasticity equal to 1)

Elasticity of demand (η)	Elasticity of supply (ϵ)											
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**2.0**	**5.0**
-0.1	-0.05	-0.07	-0.08	-0.08	-0.08	-0.09	-0.09	-0.09	-0.09	-0.09	-0.10	-0.10
-0.2	-0.07	-0.10	-0.12	-0.13	-0.14	-0.15	-0.16	-0.16	-0.16	-0.17	-0.18	-0.19
-0.3	-0.08	-0.12	-0.15	-0.17	-0.19	-0.20	-0.21	-0.22	-0.23	-0.23	-0.26	-0.28
-0.4	-0.08	-0.13	-0.17	-0.20	-0.22	-0.24	-0.25	-0.27	-0.28	-0.29	-0.33	-0.37
-0.5	-0.08	-0.14	-0.19	-0.22	-0.25	-0.27	-0.29	-0.31	-0.32	-0.33	-0.40	-0.45
-0.6	-0.09	-0.15	-0.20	-0.24	-0.27	-0.30	-0.32	-0.34	-0.36	-0.38	-0.46	-0.54
-0.7	-0.09	-0.16	-0.21	-0.25	-0.29	-0.32	-0.35	-0.37	-0.39	-0.41	-0.52	-0.61
-0.8	-0.09	-0.16	-0.22	-0.27	-0.31	-0.34	-0.37	-0.40	-0.42	-0.44	-0.57	-0.69
-0.9	-0.09	-0.16	-0.23	-0.28	-0.32	-0.36	-0.39	-0.42	-0.45	-0.47	-0.62	-0.76
-1.0	-0.09	-0.17	-0.23	-0.29	-0.33	-0.38	-0.41	-0.44	-0.47	-0.50	-0.67	-0.83
-2.0	-0.10	-0.18	-0.26	-0.33	-0.40	-0.46	-0.52	-0.57	-0.62	-0.67	-1.00	-1.43
-5.0	-0.10	-0.19	-0.28	-0.37	-0.45	-0.54	-0.61	-0.69	-0.76	-0.83	-1.43	-2.50

The demand elasticity for food in a wealthy country like Norway is relatively low. As a result, the opportunity for reductions in emissions through adjustment in total demand for food may be limited. However, changes in preferences towards lower emitting products, e.g., away from red meat towards lower-emitting meats or vegetable products could play an important role. Also price elasticities of demand are likely to be higher at the level of individual commodities, than for food as a whole. This, in combination with the effects of cross-price demand elasticities could change the structure of consumption towards lower-emitting products if prices increase as a result of a tax on production designed to reduce emissions.

On the supply side, a crucial question is what options exist for adjusting food output in response to a production tax. Two factors come in to play. First, the commodity composition of output could be changed from commodities with a large carbon footprint to commodities with lower carbon footprint. Second, more emissions-friendly techniques could be used for producing each product. In order to capture the first of these effects, we need a model that includes more than one commodity.

2.1 A multi commodity model

We now assume that the agricultural sector produces two commodities: corn and red meat. These are chosen since red meat is an example of a high emission product, while corn is a lower-emissions product. We require that all available land has to be used. And for expositional purposes we assume a simple Cobb-Douglas production structure for both commodities. The country we examine is small and follows a policy of self-sufficiency, so agriculture is protected through prohibitive tariffs. This corresponds to the situation in Norway. In the analysis the self-sufficiency policy is taken to mean that the agricultural sector in Norway has to produce a minimum amount of calories.

Corn

Corn (Q_C) is 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) $$Q_C = K_C^{\alpha_C} L_C^{\beta_C} .$$

Output can be increased by using more land or by using more capital. The effect on production of using more capital is given by α_C.

As for emissions connected to the production of corn, E_C, we assume this to be described by the formula:

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

Our motivation for (2) is as follows. In practice, the level of emissions depends on chosen production techniques. A technique that is intensive in the use of fertilizer (which is part of *K*), for example, 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 emission. Secondly, the size of production matters. We will refer to this as the *production effect*. So corn emissions are affected by the intensity in the use of *K*, and also the production level.

The relationship (2) is exceedingly simple, but it captures several key factors. In particular, if more land is used in corn farming, 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 surpass the substitution effect, i.e.

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

Cow farm

In the case of cow farming, as a representative of ruminants, red meat (*R*) is produced. The Cobb-Douglas production function is:

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

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

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

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

Aggregate relationships

For the agricultural sector as a whole we require that the amount of land used will equal the land available for farming, $\bar{L}$.

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

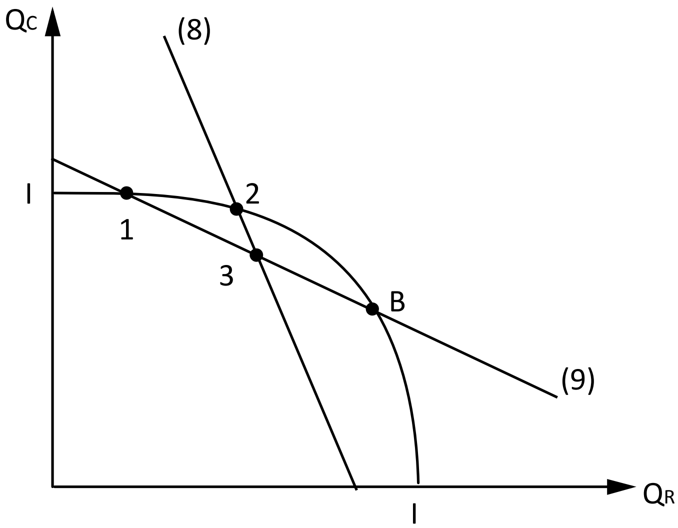
We also keep track of the calorie content from consuming Norwegian products. Denote κ_C as the per kilo calorie content of corn, and κ_R as the corresponding parameter for red meat. The population's total intake of calories from consuming food, *F*, based on Norwegian agricultural commodities is:

(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 take input prices on capital connected to the production of corn and red meat as given. Based on these assumptions we can trace out the production possibility frontier marked as I-I in Figure 2. On the vertical and horizontal axis we have quantities of corn and red meat, respectively. The base solution is marked as B. The relative price between corn and red meat, $\bar{P}_R/\bar{P}_C$, is set such that point B is reached. Note that the market prices $\bar{P}_C$ and $\bar{P}_R$ include subsidies.

Figure 2: The production possibility frontier for the agricultural sector



Total emissions, E, equal

$$E = E_C + E_R.$$

Assume now that the sector has to meet a maximum emission limitation, $\bar{E}$,

(8) $$E_C + E_R \leq \bar{E}.$$

For example, emissions may have to be decreased by 30 % compared to the base level as proposed earlier by Norway in UN climate change negotations. This restriction is drawn into figure 2 as the straight line marked as (8), and we have to be on the straight line or to the left of it. We have also to take into account the self-sufficiency requirement. We take that to mean that we have to produce at least the same amount of calories as in the base solution, F^B:

(9) $$\kappa_C Y_C + \kappa_R Y_R \geq F^B$$

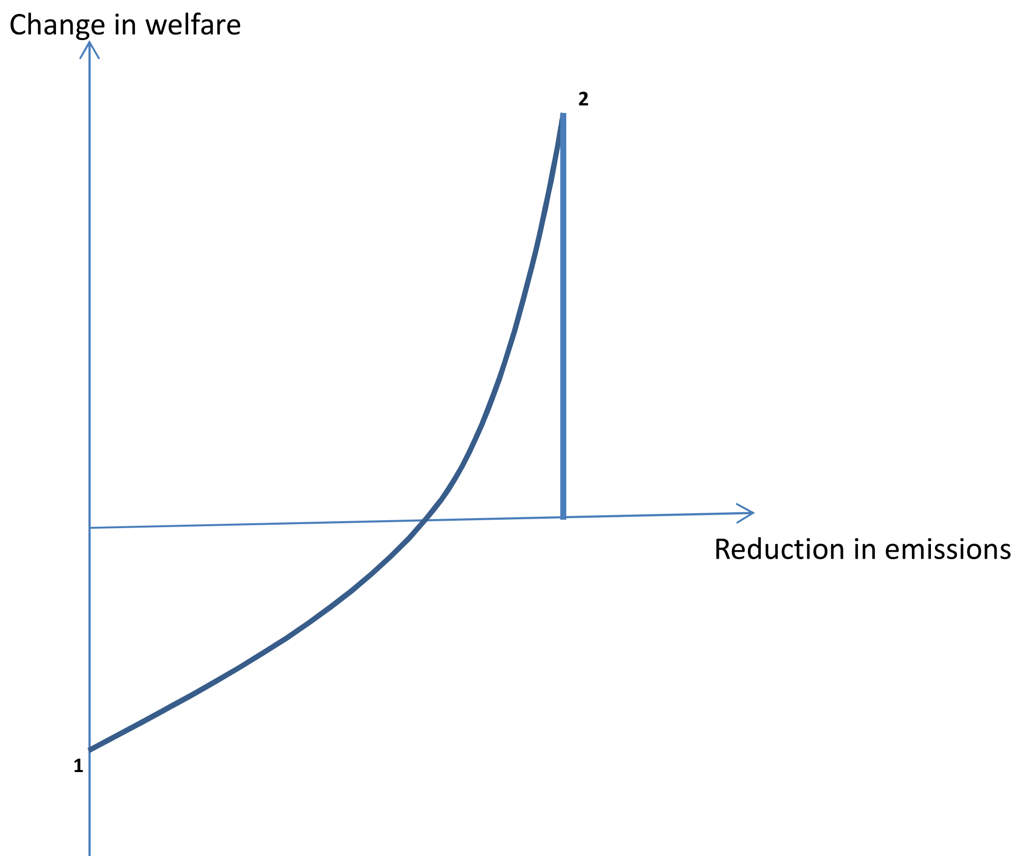
This is marked as the straight line (9) in figure 2, and we have to be on this line or to the right of it.

Given that we have to meet requirements (8) and (9), we have to choose a point within the area restricted by the points 1-2-3 in figure 2. So the problem is to find the point in that area that maximizes welfare.[1]

In Figure 3 we have drawn the abatement cost curve implied by the experiment in Figure 2. In the literature a standard abatement cost curve is drawn where the horizontal axis indicates the reduction in emissions, while the vertical axis measure the private marginal costs in production connected with those reductions. Instead of such marginal costs we use marginal changes in welfare, i.e. the vertical axis measure the change in welfare as a result of lowering emissions. In Figure 3 point 1 refers to the base solution, while point 2 marks the 30 % reduction in 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 generate lower emissions. A reduction in the use of organic soil employed 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, can be found at the upper end of the abatement cost curve.

[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).

Figure 3: Abatement cost curves



3. The model and the representation of GHG emissions

We now go beyond the simple illustration of our approach to the use of a model to determine the actual abatement cost curve for Norwegian agriculture. 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 the model has been adapted to reflect GHG emissions.

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

[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

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 the same year (National Inventory Report 2013 – Norway) was 4,311 thousand tons.[3]

---

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.

Mitigating 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. According to arguments made in footnote 6, the exchange rate is $1=7.50 NOK.
[c] Per kg of milk. Emissions from beef production are deducted (assuming 20 kg CO_2 equivalent per kg of beef).

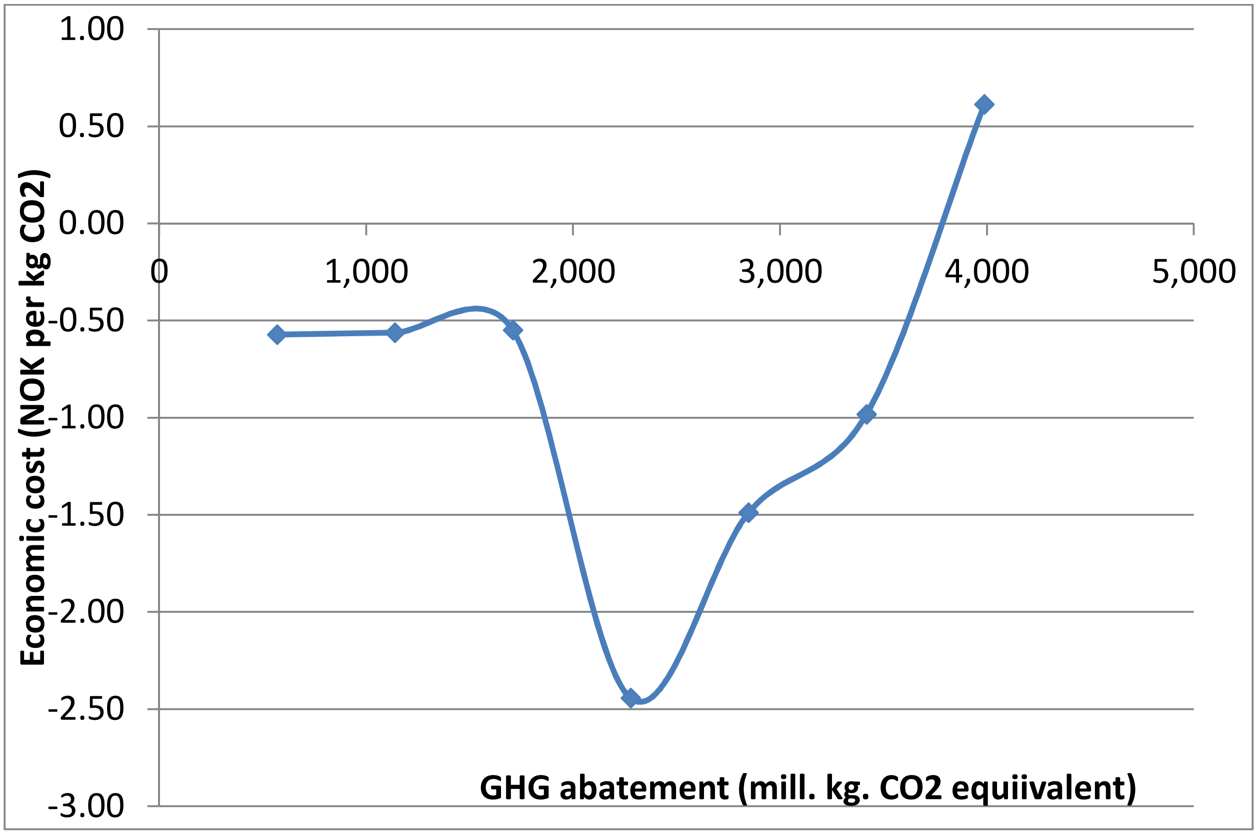
4. Results

Based on experiments using the Jordmod model we have derived a marginal abatement cost curve for Norwegian agriculture. Detailed results from the experiment are reported in Table A.1. Based on the numbers in the table we have drawn the abatement cost curves in Figure 4. The principles used to construct this are the same as in Figure 3.

Figure 4 depicts the situation in which existing government subsidy policies are continued, the current supply of calories is maintained, and a stepwise reduction in GHG emissions is imposed, each step being a 5 percentage point reduction in emissions. We start out from the base solution reported in the first column of Table A.1.

The imposition of the requirement to reduce emissions under existing support policies results in negative abatement costs. In the early phase farmers achieve the emission reduction by abandoning the use of tilled wetland. The use of tilled wetland is a significant source of emissions, but this change in production practices has a limited impact on agricultural output. There are welfare gains due to reductions in budgetary support for land taken out of production.

Figure 4: Marginal abatement cost curve under existing policies.



Once that possibility for abatement is exhausted, the next option is to reduce production of emissions intensive products, particularly beef and sheepmeat. The production of these is extremely inefficient and significant welfare gains are generated as subsidies for these activities are reduced. This accounts for the large downward dip in the MACC. Progressive reductions in ruminant production yield smaller gains in GHG reductions relative to welfare gains resulting in an upward swing in the MACC. Eventually, further GHG reductions require cutting back non-ruminant meat production and the welfare implications mean that the MACC moves above the horizontal axis.

This analysis suggests that substantial GHG reductions could be achieved in Norwegian agriculture if the existing subsidy regime were to be reformed, even if a level of domestic production were maintained to meet a calorie objective for the domestic food supply. Table 4 summarizes the results that we obtain for GHG mitigation if we undertake such a reform. Under this scenario GHG emissions from Norwegian agriculture would fall by 58 percent and the carbon footprint of food consumption in Norway would be substantially smaller.

Table 4. Comparison of results under the base solution and the policy reform solution

Production (mill kg)	Base	Reform
Cow milk	1,508	1,176
Cattle	81	36
Replaced milk cows	21	16
Combined with milk	42	20
Extensive beef	18	0
Goat milk	20	0
Sheep	24	0
Pig	130	108
Poultry	86	67
Egg	60	57
Food grain	150	300
Feed grain	951	576
Potatoes	251	256
Kcal (mill)		
Production	2,078	2,078
Feed imports	1,810	1,595
Consumption	2,592	2,301
GHG (mill kg)		
Production	5,696	2,388
Consumption	5,796	2,432
Farmland use in agricultural production (mill. ha)	0.93	0.51
Grain	0.33	0.26
Food grain	0.04	0.08
Feed grain	0.29	0.18
Grass	0.60	0.25
Tilled wetland	0.07	0.00
Farmland into sequestration (mill. ha)		
Forestry	0.00	0.00
Restored wetland	0.00	0.70
Economic welfare (mill.NOK)	6,621	10,668
Producer subsidy estimate (mill. NOK)	19,157	11,439
Budget support	11,045	1,797
Market price support (mill. NOK)	8,112	9,642

Although it is seems to be technically feasible to achieve a substantial reduction in GHG emissions from Norwegian agriculture if a radical approach were to be adopted, it is highly questionable whether such an approach would be politically feasible.

5. Conclusion

Norway is in an unusual position in terms of achieving reductions of greenhouse gases in agriculture. Due to high border protection it operates in an autarkic environment. The country is potentially able to reduce emissions without being unduly concerned about trade implications. The agricultural sector is a significant contributor to total emissions, particularly in comparison to its contribution to GDP, and it is likely that an international commitment to reduce significantly total emissions in the Norwegian economy would need to include agriculture.

If we examine emission reductions from the perspective of the impact on economic welfare, we find that emissions reductions would be welfare enhancing due to high level of support for the sector and the distortions that this creates. These distortions are reduced as greenhouse gas emissions are reduced. Although some emission reductions are possible through changes in the use of wetland, significant emission reduction would require changes in the production mix, in particular, a reduction in the production of red meat.

If existing agricultural policies were reformed, substantial reductions in GHG emissions could be achieved while simultaneously satisfying the domestic policy objective of maintaining the current supply of calories from domestic agriculture. However, this would require even greater adjustments in production and domestic consumption than under a continuation of the current high support regime.

References

Blandford, D., Gaasland I., Garcia, R. and Vårdal, E. (2010). How effective are WTO disciplines on domestic support and market access for agriculture? *The World Economy* 33: 1470-1485.

Blandford, D., Gaasland, I. and Vårdal, E. (2013). Extensification versus intensification in reducing greenhouse gas emissions in agriculture: Insides from Norway. *EuroChoices* 12(3): 4-9.

Blandford, D., Gaasland, I. and Vårdal, E. (2014). The trade-off between food production and greenhouse gas mitigation in Norwegian agriculture. *Agriculture, Ecosystems and Environment* 184: 59-66.

Brunstad, R. J., Gaasland, I. and Vårdal, E. (1999). Agricultural production and the optimal level of landscape preservation. *Land Economics* 75: 538-546.

Brunstad, R. J., Gaasland, I. and Vårdal, E. (2005). Multifunctionality of agriculture: an inquiry into the complementarity between landscape preservation and food security. *European Journal of Agricultural Economics* 32: 469-488.

Gaasland, I. and Glomsrød, S. (2010). Environmental indicators in Jordmod [In Norwegian]. Arbeidsnotat nr. 01/10. Foundation in Economics and Business Administration, Bergen.

Gardner, B.L. (1987). *The Economics of Agricultural Policies*. New York: Macmillan.

IPCC (1995). IPCC Second Assessment: Climate Change 1995. World Meteorological Organization. United Nations Environment Program.

IPCC (2007). Climate Change 2007: Synthesis Report. World Meteorological Organization. United Nations Environment Program.

Macleod, M., Moran, D., Eory, V., Rees, R.M., Barnes, A., Topp, C.F.E., Ball, B., Hoad, S., McVittie, A., Pajot, G., Matthews, R., Smith, P. and Moxey, A. (2010). Developing greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils in the UK. *Agricultural Systems*, 103, (2010): 198-209.

Morris, J., Paltsev, J. and Reilly, J. (2012). Marginal abatement costs and marginal welfare costs for greenhouse gas emissions reductions: results from the EPPA model. *Environmental Modeling & Assessment* 17: 325-336.

NILF (2007). Norwegian Agriculture: Status and Trends, *2007.* Oslo: Norwegian Agricultural Economic Research Institute.

Organization for Economic Cooperation and Development (2014). *Agricultural Policy Monitoring and Evaluation, 2014.* Paris: OECD.

Statistics Norway (2013). Emissions of greenhouse gases: 2012 preliminary figures. www.wwb.no/en/klimagassn. Accessed November 5, 2013.

WTO (2001). *World agriculture negotiations: Proposal by Norway*. Document no. G/AG/NG/W/101 Geneva: World Trade Organization, WTO Secretariat, Committee on Agriculture, Special Session, 16 January.

WTO (2004). *Trade policy review: Norway*. Report by the WTO Secretariat, Document no. WT/TPR/S/138. Geneva: World Trade Organization, Trade Policy Review Body, 13 September.

Table A.1: Jordmod experiments. Required reduction of GHG-emissions under existing support policies

	Base	*100 %*	*90 %*	*80 %*	*70 %*	*60 %*	*50 %*	*40%*	*30%*
Production (mill kg)									
Cow milk	1,508	1,508	1,507	1,507	1,507	1,471	1,426	1 ,377	1,007
Cattle	81	81	78	75	73	57	40	23	14
Replaced milk cows	21	21	21	21	21	20	20	19	14
Combined with milk	42	42	42	42	42	37	20	4	0
Extensive beef	18	18	15	13	10	0	0	0	0
Goat milk	20	20	20	20	20	19	19	18	12
Sheep	24	24	23	21	20	14	7	0	0
Pig	130	130	130	129	128	125	119	114	67
Poultry	86	86	86	86	85	82	79	75	37
Egg	60	60	60	60	60	59	58	57	49
Food grain	150	150	153	156	159	183	213	245	386
Feed grain	951	951	933	916	899	807	717	627	316
Potatoes	251	251	251	251	251	250	247	244	293
Kcal (mill)									
Production	2 078	2 078	2 078	2 078	2 078	2 078	2 078	2 078	2 078
GHG (mill kg)									
Production	5,696	5,696	5,126	4,557	3,987	3,418	2,848	2,278	2,078
Farmland in production (mill. ha)	0.93	0.93	0.91	0.88	0.86	0.74	0.63	0.52	0.39
Grain	0.33	0.33	0.33	0.32	0.32	0.30	0.28	0.26	0.21
Food grain	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.10
Feed grain	0.29	0.29	0.29	0.28	0.28	0.25	0.23	0.20	0.11
Grass	0.60	0.60	0.58	0.56	0.54	0.44	0.35	0.25	0.18
Tilled wetland	0.07	0.07	0.05	0.02	0.00	0.00	0.00	0.00	0.00
Farmland into sequestration (mill. ha)									
Forestry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Restored wetland	0.00	0.00	0.02	0.05	0.07	0.07	0.07	0.07	0.07
Economic welfare (mill.NOK)	6,621	6,621	6,947	7,268	7,581	8,973	9,822	10,381	10,032
Producer subsidy estimate (mill. NOK)	19,157	19,157	18,978	18,798	18,618	15,842	13,885	11,922	9,060
Budget support	11,045	11,045	10,762	10,492	10,237	6,890	4,372	3,092	53
Market price support (mill. NOK)	8,112	8,112	8,216	8,306	8,380	8,953	9,153	8,830	9,007
CO2 tax rate (NOK per ton CO2 equiv.)	0	0	13	26	39	716	1,219	1,720	16,565
Kcal subsidy rate (NOK per 1000 Kcal)	0.00	0.00	0.05	0.11	0.16	0.44	0.56	0.66	18.86