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Greenhouse Gas Emissions in Norwegian Agriculture: The Regional and Structural Dimension

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Abstract: This paper studies the hypothesis that farm structure and the regional distribution of agricultural activity themselves have a significant impact on greenhouse gas (GHG) emissions from agriculture. Applying a dynamic model for the Norwegian agricultural sector covering the entire farm population, the model results support the hypothesis. Even without mitigation options, GHG emissions decline by 1.4 per cent if agriculture becomes regionally concentrated and increase by 1.5 per cent if a policy that favors a small-scale farm structure is put in place. Adding a carbon tax to a policy that leads to regional concentration, may help to reconcile competing policy objectives. A switch from animal production to crop production, and an extensification of animal production keeps a large resource base across the country while cutting GHG emissions.

Keywords: climate change; carbon tax; modelling; policy reform

1. Introduction

Norwegian agricultural policies pursue various objectives such as increasing food production, maintaining agricultural activity all over the country, securing a diverse farm structure with small and medium-sized farms, and ensuring income development comparable to other groups in society. While some policy objectives reinforce each other, some are conflicting. The reduction of greenhouse gas (GHG) emissions adds to this complexity. In June 2019, the government and the farmers' organizations signed a voluntary agreement to reduce GHG emissions by five million tons from agriculture between 2021 and 2030 [1]. This ambition corresponds to about 10 per cent of the expected agricultural GHG emissions in that period. The concrete climate actions taken to achieve this goal are disputed and remain unclear. A potential conflict of GHG emission reductions and other agricultural policy objectives has so far been discussed at the national level [2,3]. This paper contributes to this knowledge gap by questioning the extent to which the regional distribution of agricultural activity and changes in farm size affect GHG emissions from agriculture.

The hypothesis of this paper is that the farm structure and the regional distribution of agricultural activity have a significant impact on GHG emissions from agriculture. The regionalized agricultural sector model Agrispace that comprises the entire Norwegian farm population [4], is applied to a series of structured scenarios. Agrispace is particularly useful for this research question as it provides a dynamic perspective and avoids regional specialization effects associated with comparable models like Jordmod [2]. Agrispace is extended to account for GHG-emission, which was lacking in the original version of the model. The mode was therefore extended before being applied to the scenarios.

Previous research indicates that significant GHG emission reductions cannot be achieved without compromising food production and land use. Using the Jordmod model, a partial equilibrium model for the Norwegian agricultural sector, Blandford et al. [3] showed that a 30 per cent emission cuts comes along with a 23 per cent reduction in food production and an equally high reduction in land use. Mittenzwei, also using Jordmod, received similar results [5].

The remainder of the paper is organized as follows. Section 2 gives a short overview of the model and presents the extension of Agrispace with GHG emission accounting. Scenarios are introduced at the end of the section. Section 3 reports the key results of the model simulations on GHG emission reductions, production and input use, farm size, welfare impacts and regional distribution. We conclude and discuss caveats of the approach in the final section.

2. Materials and Methods

2.1. Overview

Agrispace is a recursive-dynamic and spatial multi-commodity model used for ex-ante policy analysis for the agricultural sector in Norway [5].

The model is based on the standard approach of competitive markets, profit maximizing producers and utility maximizing consumers. The agricultural sector is assumed to be small and open where prices for international food commodities and prices for inputs outside the sector are fixed. Markets for agricultural inputs and outputs are cleared resulting in regional prices and inter-regional trade flows. A detailed technical and methodological documentation can be found in the online model documentation [6]. The remainder of this section follows closely the model's description in [5].

2.2. Supply

The model distinguishes 32 regions that are homogenous with respect to payment rates and natural conditions to ensure very similar crop yields [7]. Furthermore, each region is divided into 4 to 16 clusters of individual farms which are modelled by aggregate production and factor supply functions. The farm clusters are derived by statistical analysis from the entire population of 42,180 farms applying for subsidies in the 2014 calendar year. Each cluster represents an average of about 140 farms.

The model differentiates 19 agricultural products (e.g., cereals, fruits and vegetables, milk, beef, pork, poultry and eggs) and 6 input categories (capital, various types of land, labor, intermediate inputs including roughage and feed concentrates). Product-specific technology of each farm cluster is modelled by nested constant elasticity of substitution (CES) production functions. This specification allows for substitution between inputs and assumes constant returns to scale.

At the farm cluster level, production activities compete for a composite commodity comprised of capital and labor, and three land categories. This competition is described by constant elasticity of transformation (CET) functions, which imply different input qualities in the different productions in one aggregate farm. Hence, factor returns can differ. The farm cluster's total supply of capital and labor is modelled through a linear relationship that depends on average returns and on-farm and off-farm prices.

The regional land market consists of explicit land supply functions and implicit demand functions from the farm clusters. Land is distributed to the farm clusters implying that land markets are not perfect as returns between the cluster farms can vary.

Feed demand differentiates various types of feed inputs such as soy cake, and cereals. Farm produce is processed further in the value chain. Raw milk is processed into different dairy products such as fresh milk, cheese, butter, and milk powder with endogenous margins. For all other products, fixed processing margins apply.

Structural change happens through on and off-farm changes in labor and capital and competition in land markets between farm groups. The model also generates changes in production, demand, trade and prices at the national level.

Simulated changes in output quantities and land use at the farm cluster level are mapped in each year into each single farm. This is necessary in order to re-calculate subsidies (as payment rates differ with respect to farm size and region) and to estimate farm exit. Subsidies are differentiated according to the categorization of PSE data by the OECD [8]. The mapping between the markets, farm clusters, and single farms ensures consistency between micro level and the partial equilibrium model results at the sectoral level. Changes in labor and capital costs at the micro level reflect simulated changes in production output level and cost shares of each individual farm.

Farm exit depends on a farm size specific profit cut-off level and a stochastic component. The profit cutoff accounts for the observation that small farms and different production often receive lower returns on labor and capital. On average, 27 per cent of all farmers have negative taxable income from agriculture for each year between 2004 and 2015. Only 1700 farmers exit the sector [9]. More than half of the farms with less than 0.5 ha of land have negative taxable income from agriculture in 2015. In contrast, that was true for only 8 per cent for farms with more than 50 ha [10]. The cut-off level starts with a profit of € 25,000 for farms with less than 0.1 ha and increases linearly to a profit of €2500 for farms with 20 ha of land. Thereafter, the cut-off level remains constant irrespective of farm size. The model randomly disturbs the cut-off level for each farm to reflect non-economic impacts (e.g., accidents, illness or unexpected off-farm opportunities). Annual changes in profits enter the standard deviation of the stochastic term. A drop (or increase) in farm profit increases (or decreases) the standard deviation and thus increases (or decreases) the probability of a farm exit. Hence, exit conditions reflect both the size of individual farm's profit and its yearly change. The parameters of the profit cut-off level mirror the observed structural change. In a final step, changes in production and land resulting from farm exit are mapped back to the cluster level.

2.3. Calculation of GHG emissions

GHG emissions in agriculture originate from biological processes. GHG emissions per unit of output or per unit of factor input may vary considerably between farms [11–13]. The variation is caused by stochastic factors (e.g., soil type, weather, and other natural conditions) and management decisions (e.g., choice of the production technology).

GHG emission data at the farm level in Norway are sparse, but availability is continually increasing through research. Calculations are available for dairy farms [11], farms with pig production [12], and crop farms [13]. The three studies included GHG emissions of imported feed stuffs. Life Cycle Analysis (LCA) on dairy and meat production for a selected number of farms are also performed [14,15]. Unlike the farm level analysis, which only measures GHG emissions originating at the farm, the system boundaries of LCA are broader as they include the GHG emissions of all farm input—national or foreign. It is therefore challenging to directly use GHG emission estimates in studies that follow the territorial approach and are limited to a specific emission sector.

While the above-mentioned studies consider important productions, some productions are missing (i.e., suckler cow, laying hens, chicken, vegetables and fruits). Moreover, results for individual farms are not available, making it difficult to estimate a link among GHG emissions, geographic location and size at farm level. To address this issue, Jordmod is used to systematically calculate GHG emissions for various types of farms with different farm sizes in 32 regions. Jordmod distinguishes between farms for cereals, potatoes, vegetables, fruits, dairy, beef meat from suckler cows, sheep, pork, poultry and eggs. For this work, the model's farm module is used by calculating GHG emissions for all 11 farm types in 32 regions, distinguishing 7 different farm sizes which makes a total of about 2400 observations at the farm level [16].

These data are then used to estimate the empirical relationship between GHG emissions, animals and farm land. The functional form follows a power function where the average GHG emissions per animal or land unit are given by:

$$\mathrm{GHG}_{(i,r)}/\mathrm{LEVL}_{(i,r)} = a_{(i,r)} \times \mathrm{LEVL}_{(i,r)}{}^{b(i,r)} \tag{1}$$

where LEVL(i,r) denotes the level of activity i in region r, and a(i,r) and b(i,r) are coefficients of the power function and GHG(i,r) are the total GHG emissions of activity i in region r. The functional form allows to differentiate GHG emissions at the farm level by region and farm size. The specification of GHG emission accounting implies that lower emissions can be achieved either through reduced production or through a change in the mix of inputs, e.g., if the same amount of milk is produced with less or more dairy cows.

GHG accounting in Jordmod follows to a great extent the guidelines used in the official reporting of Norwegian GHG emissions to the United Nations (UN) in the framework of the UNFCCC (United Nations Framework Convention on Climate Change), the so-called National Inventory (NIR) [17]. The NIR and Jordmod cover those GHG emissions that accrue from agricultural production on Norwegian territory only. They do not, for example, account for GHG emissions of inputs to Norwegian agriculture sourced from foreign countries. Some methodological differences apply. Jordmod has fewer animal categories than the NIR and it does not cover non-agricultural animals like reindeer and deer. The total GHG emissions in Jordmod in the base year (average between 2013 and 2015) are 3.2 per cent lower than the emissions reported in the NIR for that period.

The accuracy of the estimation procedure is investigated by comparing the results obtained in the Jordmod model with the model results in the literature for dairy, pork and cereals. Table 1 shows the model results for GHG emission coefficients per unit of output for cereals, cow milk and pork meat, and compares these results with findings from the literature.

Table 1. Comparison of greenhouse gas (GHG) emission coefficients in Jordmod and the literature for cereals, cow milk and pork meat (kg CO_2-eq per kg or ltr).

	Jordmod			**Literature 1)**		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
Cereals	0.397	0.296	0.911	0.433	0.291	0.727
Cow milk	1.506	1.366	1.844	1.224	1.104	1.624
Pork	1.327	1.326	1.328	1.140	0.290	2.900

1) Own calculation based on [11] for dairy, [12] for pork, and [13] for cereals.

Note that Jormod's results are based on the average between 2013 and 2015, while the results from the literature are based on data well before 2010. Nevertheless, it appears that the estimated values for cereals are very much in line with the reported results in [13] both for the mean and the extreme values (min and max). The results for cow milk and pork are, on the contrary, different from the values in the literature. The mean value for cow milk in Jordmod is 23 per cent higher than the corresponding value in [11]. It is, however, within the reported range. For pork, there is no variation in Jordmod, and the mean value is 16 per cent higher than the corresponding value in [12]. The literature reports a large variation for pork meat, which is mainly caused by N_2O emissions from soil [12].

Finally, the estimated GHG emission coefficients are transformed into coefficients per animal head or land using base year values from 2014. They then enter the Agrispace model in the calculation of GHG emissions and in the calculation of the carbon tax applied at the farm level. Animal herds are only used in Agrispace to ensure the correct calculation of subsidies for animals at the farm level. They do not enter the production function nor the profit maximization at farm level to prevent complexities such as dynamic calculations to ensure a consistent development of animal categories and the herd size over time. Instead, animal payments are converted into output payments for milk, meat and egg. Milk yields and slaughter weights are assumed to remain constant during simulations. This way the animal herds change in the same way as production.

2.4. Demand

Agrispace considers commodities as homogenous, such that price differences in space depend on transport margins and policy instruments. The model set-up reflects spatial arbitrage, i.e., price differences between two regions are restricted to the bi-lateral per unit transport and transaction costs. In order to perform consistent welfare analysis, (semi-)flexible functional forms ensure global adherence to regularity conditions. A generalized Leontief (GL) expenditure system drives final demand. The system has the advantage that curvature can be easily imposed globally. The GL system is based on indirect utility functions that depend on consumer prices and income, and it allows for own and cross-price effects.

2.5. Welfare

As mentioned in the previous section, the demand system of Agrispace allows consistent welfare analysis. The model distinguishes the welfare of consumers, producers (including the food industry), owners of agricultural inputs (e.g., labor, land, and capital), and tax payers. Farmers who own their land and capital are both producers and owners of agricultural inputs.

2.6. Technical Implementation

In line with other tools [18], Agrispace is coded in GAMS (General Algebraic Modelling System, [19]). CONOPT [20] is used for the Bayesian based parameter calibrations, while the market model is solved in PATH [21]. A Graphical User Interface allows steering the model and results exploitation, which is implemented in GGIG (GAMS Graphical Interface Generator [22]).

2.7. Scenarios

A structured set of five scenarios is developed to study the effects of changes in the regional distribution of production, input use, and farm size on GHG emissions (Table 2). Each scenario differs from each other with respect to the level of governmental intervention. Two payments systems are considered: (1) a "uniform" payment systems in which all payment rates are transformed into uniform payment rates irrespective of farm size or farm location under the condition that the payment rates do not change the overall budget, (2) a "distinct" payment system in which all payment rates are increased by 25 per cent and all payments are capped above a certain threshold. Such a capping is in place in the base year for two types of payments, and in the scenarios extended to all payment types. The level at which the payments are capped is chosen to prevent an extraordinary rise in budget support to agriculture in the simulations, while at the same time ensuring that production and input use still can take place all over the country. In addition, milk quotas are abolished in the uniform payment system to allow for a non-governmental regulated distribution of milk production. Milk quotas in Norway are tied to the farm and are tradable within a county.

Table 2. Overview of the scenarios.

	Continuation of Current Policies	**Uniform Payment System, Abolition of Milk Quota**	**Distinct Payment System, Maintaining of Milk Quota**
No carbon tax	Baseline	Uniform	Distinct
Carbon tax	CT	Uniform_CT	Distinct_CT

CT: Carbon tax.

Moreover, a carbon tax is implemented as a climate mitigation option. Farmers react to the carbon tax by redirecting the production mix at the farm level towards less emission intensive outputs or by changing the production technology, e.g., changing the input mix to produce a given quantity of output. The carbon tax is implemented with a rate of €60 per ton CO_2-eq, which compares to the anticipated price of a carbon tax in about 2030.

This makes a total of five scenarios in addition to the baseline which is modelled as a continuation of current policies.

Trade policies are kept unchanged in all scenarios. This is because the scenarios study domestic policy reform only. The most important exogenous assumptions across all scenarios regard population growth (+ 1 per cent p.a. at national level, using regional projections where growth rates differ), income growth (+ 2 per cent p.a.), and world market prices (−2 per cent p.a.). Furthermore, wage rates are assumed to increase at 2 per cent p.a. and returns to capital at 1.5 per cent p.a. Results are compared to a baseline scenario ("Baseline") in which payments and milk quotas are kept at their base year levels, while the above-mentioned exogenous assumptions are implemented over the simulation period.

The base year of Agrispace is 2014, and the simulation year can be chosen freely. For the purpose of this study, a simulation period of 11 years seems appropriate as it covers the number of 9 years of the first reporting period 2021 to 2030. The final simulation year is hence set to 2025 allowing for an adjustment period after the policy change for 10 years.

3. Results

Key results of the simulation from Agrispace are shown in Table 3. Values are presented as percentage deviations from the baseline in 2025.

Table 3. Key simulation results in 2025 (percentage (points) deviation from baseline).

Indicator	CT	Uniform	Uniform_CT	Distinct	Distinct_CT
Production	−2.0%	−0.6%	−5.0%	0.6%	−1.3%
Land use	−1.7%	−1.4%	−3.2%	−0.1%	−0.9%
LFA share of land use [1)]	−0.16	−0.37	−0.95	0.24	0.17
GHG emissions	−3.2%	−1.4%	−9.2%	1.5%	−1.0%
Structural change	−3.6%	−6.1%	−12.1%	5.1%	3.1%
Farm size	1.9%	5.0%	10.2%	−5.0%	−3.9%
Agricultural support	−3.5%	−16.3%	−21.6%	8.1%	5.7%
Total welfare	0.3%	0.1%	0.6%	−0.1%	0.1%

1) Percentage points. CT: Carbon tax; LFA: Less favorable agriculture. Source: Own calculations.

Production, measured as the value of production in constant 2014-prices, decreases in all scenarios except from scenario "Distinct" that shows a slight increase. Scenarios with a carbon tax experience a larger reduction in production. The effect is more pronounced in scenario "Uniform" with a difference of 4.4 percentage points, while that difference is much less in the two "Distinct"-scenarios with 1.6 percentage points. A reason might be that the introduction of a carbon tax works in the same direction as a shift of the payment system towards more uniform payment rates.

The effects of the policy change on land use mirror those on production, but to a lesser extent. Land use decreases in all scenarios, but the reduction is less pronounced. At the most, land use is 3.1 per cent lower compared to the baseline. The results may hint towards some extensification in production or a change towards more land-intensive productions.

The change in the share of land use in less favorable agricultural (LFA) regions is defined as the percentage point deviation from the corresponding share in the baseline in 2025. The share increases somewhat in the «Distinct»-scenarios and decreases a little more in the «Uniform»-scenarios. The overall change is less the one percentage point. The implementation of a carbon tax only has little effect on the share of land use in LFA-regions.

GHG emissions decrease in most scenarios. The carbon tax provokes the largest emission reductions, but emissions are also reduced in the «Uniform»-scenario without a carbon tax by 1.4 per cent. Similarly, emissions increase in the «Distinct»-scenario without a carbon tax by 1.5 per cent. This indicates a close relationship between the regional distribution of production and land use on the one hand and GHG emission reductions on the other hand. Emissions are also reduced in the «Distinct»-scenario, but only if the policy change is accompanied by a carbon tax. The reduction is still smaller than in the «Uniform»-scenario.

The two different policy options provoke a significantly different path of structural change. In the «Uniform»-scenarios, the decrease in the number of farms between 2014 and 2025 is 6 to 12 percentage points higher compared to the base line. In contrast, farm exit is 3 to 5 percentage points lower in the «Distinct»-scenarios than in the baseline. This observation is mirrored in the development of the farm size. Farms in the «Uniform»-scenarios are 5 to 10 per cent larger than farms in the baseline, while farms in the «Distinct»-scenarios are 4 to 5 per cent smaller.

Budget support to agriculture shows considerable differences with respect to the policy options. The introduction of a carbon tax only reduces budget support by 3.5 per cent compared to the base line, while support decreases by 16 to 22 per cent in the «Uniform»-scenarios. In the «Distinct»-scenarios, however, support increases by 6 to 8 per cent compared to the baseline in 2025.

Total social welfare seems rather unaffected across scenarios. Relative changes are below one per cent compared to the baseline. Welfare increases slightly in all scenarios where are a carbon tax is introduced. The impact is highest (0.63 per cent) when the carbon tax is combined with uniform payments. In addition, welfare increases in the «Uniform»-scenario without a carbon tax. In the «Distinct»-scenario without a carbon tax, welfare decreases slightly. However, introducing a carbon tax in this scenario results in a positive welfare outcome.

Table 4 details the results on the relationship among production, input use and GHG emissions in ruminant production. GHG emissions in milk and beef production and sheep production are decomposed into a production effect and an input substitution effect. The calculation of that decomposition is not straightforward as the model treats individual farms and farm clusters with multiple inputs and outputs. Tracing the change in the technology of a specific production is therefore not possible. For milk and beef production, the production value in the baseline has been divided by the GHG emissions from milk and beef to calculate the emission intensity (2.138 kg CO_2-equ per €). The "production effect" in Table 4 shows how much GHG emissions had changed in the respective scenarios if the emission intensity is the same as in the baseline. The difference between the absolute change in GHG emissions and the "production effect" is called the "input substitution effect" and can be accrued to a change in the input mix. For sheep production, the production quantity is used instead of the production value, while the calculation of the production effect and input substitution effect remains the same. Most of the GHG-emission reductions are caused by a decrease in production. This effect is most pronounced in all scenarios with a carbon tax.

Table 4. Change in GHG-emissions by production and scenario in 2025 (kt CO_2-equ).

	Milk and Beef Production		Sheep Production	
	Production Effect	**Input Subst. Effect**	**Production Effect**	**Input Subst. Effect**
CT	−75.6	−3.5	−50.4	−1.0
Uniform	−66.9	3.5	0.6	−0.5
Uniform_CT	−348.0	−25.3	−37.2	−0.8
Distinct	28.1	1.5	26.9	0.6
Distinct_CT	−40.0	5.1	−12.5	0.0

CT: Carbon tax; t: tons; kt: 1000 tons; CO_2-equ.: CO_2-equivalents. Source: Own calculations.

Table 5 shows results for GHG-emissions by emission source. CO_2-emissions are caused by fertilizer application and this changes little between scenarios. The relative reduction of CO_2-equ. compared to the baseline in 2014 varies between 3.4 and 13.5 per cent. Emissions of nitrous oxide (N_2O) are reduced most in the «Uniform» with a carbon tax scenario (14.7 per cent). A considerable share of this reduction is stimulated by the carbon tax as N_2O-emissions go down by 9.2 per cent in the carbon tax alone scenario. The emissions of methane (CH_4) remain unchanged in the «Distinct» without the carbon tax scenario as compared to the baseline. Methane emissions are reduced most in the «Uniform» with a carbon tax scenario with 11 per cent compared to 2014. Less than half of that reduction is caused by the carbon tax as shown by the 4.4 per cent reduction of CH_4 emissions when the carbon tax is applied alone. This indicates that a switch to uniform payments in the presence of a carbon tax has a larger effect on reducing CH_4 emissions than on reducing N_2O emissions.

Table 5. Greenhouse gas emissions by scenario and source in 2025 and change from baseline in 2014.

Indicator	Total Emissions		CO_2		N_2O		CH_4	
	(kt CO_2-eq.)	% chg.	(kt)	% chg.	(t)	% chg.	(kt)	% chg.
Baseline	4 575	−4.8%	444	−17.6%	6 304	−5.9%	90	−1.1%
CT	4 427	−7.9%	438	−18.7%	6 084	−9.2%	87	−4.4%
Uniform	4 513	−6.1%	442	−18.0%	6 185	−7.6%	89	−2.2%
Uniform_CT	4 156	−13.5%	439	−18.6%	5 713	−14.7%	81	−11.0%
Distinct	4 644	−3.4%	452	−16.1%	6 411	−4.3%	91	0.0%
Distinct_CT	4 531	−5.7%	451	−16.3%	6 244	−6.8%	89	−2.2%

CT: Carbon tax; t: tons; kt: 1000 tons. Source: Own calculations.

The overall composition of the three sources of GHG-emissions in agriculture remains rather constant across all scenarios. Methane causes about 50 per cent of the total GHG emissions, while N_2O contributes with 40 per cent and CO_2 with the remaining 10 per cent.

Table 6 indicates the changes in production in 2025 caused by the different policy options underlying the different scenarios. Cereals production increases significantly in the «Distinct»-scenarios irrespective of a carbon tax. Milk production is maintained at baseline levels in all scenarios besides the «Uniform» with a carbon tax scenario. In this scenario, milk production is reduced by 10 per cent from 1524 mill. kg to 1358 mill. kg. This also has an impact on beef production, which is down by 14 per cent in "Uniform_CT" compared to the baseline. The introduction of a carbon tax leads to 8 to 10 per cent lower beef production in both "Uniform"- and «Distinct»-scenarios. This is the same percentage change as in the scenario with the carbon tax only, indicating that the reduction in beef production is mainly driven by the carbon tax, and not by a change in policies.

Table 6. Production by scenario in 2025 (mill. kg).

Scenario	Cereals	Milk	Beef	Sheep	Pork	Poultry	Eggs
Baseline	719	1 524	79	23	145	118	70
CT	714	1 524	73	21	141	118	70
Uniform	717	1 509	75	23	147	118	70
Uniform_CT	712	1 358	68	22	144	119	70
Distinct	746	1 523	82	24	144	118	69
Distinct_CT	745	1 523	76	23	140	118	69

CT: Carbon tax. Source: Own calculations.

Like beef production, sheep production experiences a similar development with larger reductions in case of the use of a carbon tax. The magnitude of the relative changes is, however, somewhat smaller compared to beef. Pork production is also somewhat affected by the carbon tax, while there are insignificant changes in all scenarios compared to the baseline when it comes to poultry and egg production.

The impact of the policy options on the development of the number of farms and farm size is presented in Table 7. The largest impact is observed in scenario "Uniform_CT" where the annual reduction of the number of farms is 3.33 per cent compared to 2.20 per cent in the base year. Consequently, farm size increases to about 40.3 ha in that scenario compared to 36.5 ha in the baseline. Farms are smaller than in the baseline in both «Distinct»-scenarios with around 35 ha. In these two scenarios structural change slows down to 1.8 to 1.9 per cent annually between 2014 and 2025.

Table 7. Farm development and farm size by scenario in 2025.

Scenario	No. of Farms at End of Year	Annual Percentage Change 2014-2025	Farm Size (ha)	Farm Size in Per Cent of Baseline
Baseline	26 248	−2.20	36.54	100%
CT	25 315	−2.50	37.22	102%
Uniform	24 645	−2.76	38.37	105%
Uniform_CT	23 062	−3.33	40.25	110%
Distinct	27 592	−1.75	34.71	95%
Distinct_CT	27 072	−1.91	35.11	96%

CT: Carbon tax; t: tons; kt: 1000 tons. Source: Own calculations.

Table 8 shows changes in land use and farm management illustrated by the livestock density. Arable land remains stable and seems little affected by the policy changes depicted in the scenarios. On the contrary, the amount of agricultural area devoted to pasture is affected both by the introduction of a carbon tax and the policy reforms. The carbon tax has a larger impact on pasture as livestock is more affected by a carbon tax than other animals.

Table 8. Farm development and farm size by scenario in 2025 (1000 ha or LU per ha).

Scenario	Total Agricultural Area	Arable Land	Pasture	Livestock Density
Baseline	959	294	654	0.56
CarbTax (CT)	942	294	637	0.54
Uniform	946	293	641	0.55
Uniform_CT	928	293	624	0.52
Distinct	958	292	655	0.58
Distinct_CT	950	292	647	0.54

CT: Carbon tax; t: tons; kt: 1000 tons; LU: Livestock units. Source: Own calculations.

The introduction of a carbon tax leads to a moderate extensification of livestock production. The livestock density is two and four percentage-points lower in scenarios that include a carbon tax compared to those without it (Table 8). The reason is that subsidies are tied to either output or land with a majority being land-based payments. Hence, farmers choose to keep their land rather than output (i.e., animals) as part of their adjustment induced by the carbon tax. Livestock is calculated based on the numbers of animals in 2014, and assuming a one per cent annual increase in slaughter weights until 2025.

A selection of economic variables is presented in Table 9. Total welfare remains mainly unchanged. Consumer surplus, and hence, food demand stays constant across scenarios. The carbon tax, as implemented in the scenarios, has a very limited impact on food prices and leads foremost to "carbon leakage", i.e., domestic production is replaced by imports.

Table 9. Total welfare, subsidies and carbon tax (mill. €).

Scenario	Welfare	Subsidies	Carbon Tax
Baseline	384 672	1 573	0
CarbTax (CT)	385 695	1 518	222
Uniform	385 193	1 317	0
Uniform_CT	387 077	1 233	206
Distinct	384 180	1 700	0
Distinct_CT	385 103	1 662	227

CT: Carbon tax; t: tons; kt: 1000 tons. Source: Own calculations.

Subsidies are considerably higher in the two «Distinct»-scenarios compared to the baseline and the two «Uniform»-scenarios as profitability is lower for smaller farms. The farms require higher subsidies to remain in the sector. However, the value of the subsidies is very small compared to the overall social welfare. The carbon tax amounts to about 200 million €, which again is a small amount relative to the subsidies.

Finally, Table 10 presents the changes in the regional distribution of key variables based on the different scenarios. The numbers in the table refer to the share of LFA- regions, which are defined as regions with less favorable natural conditions for agriculture. They consist of all regions except the Eastern Lowlands, the South-Western Lowlands (Jæren) and the Central Lowlands. LFA regions in Norway should not be confused with the concept of less-favored areas in the Common Agricultural Policy of the European Union.

Table 10. Share of less favorable agricultural (LFA) regions for key variables in 2025 (%).

Scenario	GHG-Emissions	Cereals	Milk	Meat & Egg	Land Use	Farms	Subsidies
Baseline	58%	16%	66%	39%	55%	68%	67%
CarbTax (CT)	58%	16%	66%	38%	55%	67%	67%
Uniform	55%	16%	61%	38%	55%	65%	59%
Uniform_CT	54%	16%	61%	38%	54%	64%	58%
Specific	58%	16%	66%	39%	55%	67%	67%
Specific_CT	58%	16%	66%	38%	55%	67%	67%

CT: Carbon tax. Source: Own calculations.

Rural areas cause 58 per cent of agriculture's GHG emissions in the baseline. With the carbon tax, the amount decreases to 54 per cent in the «Uniform» with the carbon tax scenario. This has the most significant distributional consequences for production. Cereal production is mostly located in regions with favorable natural conditions for agriculture. The share of LFA-regions is unaffected by the scenarios. Milk production shows the largest change in the regional distribution of production. LFA-regions produce five percentage points less milk in the two «Uniform»-scenarios compared to the baseline and the «Distinct»-scenarios where the share remains constant. This effect can be attributed to the abolition of the milk quota. The regional distribution of meat and egg is much less affected than that of milk. A similar development can be observed for agricultural area.

Larger differences can be observed in terms of the regional distribution of farms. In the «Uniform» with the carbon tax scenario, the share of farms in LFA-regions declines to 64 per cent, which is four percentage points lower compared to the baseline. The share of subsidies that are directed to LFA-regions remains constant in the «Distinct»-scenarios compared to the baseline (67 per cent). Moreover, the subsidy shares also shrink to 58 to 59 per cent in the two «Uniform»-scenarios. The overall picture suggests rather small changes in the regional distribution of the different variables describing agricultural activity. The reason is twofold. Firstly, production cannot easily move from LFA-regions to favorable agricultural regions due to limited land resources are available to expand agriculture. This is especially true when agricultural activity remains constant at the national level. Secondly, the increase in subsidies in the «Distinct»-scenarios and the sharpened regional profile of the payment rates prevents agricultural production to move into favorable agricultural regions.

4. Discussion

This paper addresses the question of the relationship among GHG emissions, the regional distribution of agricultural activity and farm structure. A series of simulations is applied to a dynamic model for the Norwegian agricultural sector covering the entire farm population to quantify the impact of different policy options on this relationship.

The model results support the hypothesis, although in opposite directions: a policy reform that leads to a concentration of agricultural activity in favorable agricultural regions, achieves a moderate decline in GHG emissions, while a policy reform in favor of small farms yields higher GHG emissions. This could be explained by a change in the composition of agricultural production induced by the implied policy changes. Uniform payment rates deter animal production in less-favorable areas twice as farms in the regions are smaller and no longer benefit from regionally and structurally differentiated payment rates. Animal production moves to more favorable agricultural areas. Less GHG-emitting crop production increases at the national level to the expense of animal production. A carbon tax reinforces the effects of a regionally concentrated agriculture, while it reverses the effect of a small-scale farm structure on GHG emissions. The combined effect of a carbon tax and a more regionally concentrated agriculture (−9.1 per cent) on GHG emissions is larger than the sum of the two single effects (−3.1 per cent and −1.4 per cent). Interestingly, this result only holds for GHG emissions. The combined effect on production and land use is not larger than the sum of the two single effects. This indicates that emission cuts can be achieved without reducing production and land use to the same extent. The production effect is largest in a situation with uniform payments and a carbon tax ("Uniform_CT") with a decrease of five per cent. However, this does not mean an equal reduction in food production or degree of self-sufficiency. As animal production is partly replaced by crop production, the effect on the calorie production of Norwegian agriculture is less than five per cent.

The GHG emission reductions do not satisfy the reduction target in the voluntary agreement between the government and the farmers associations. Additional mitigation options and/or a higher carbon tax would be needed to yield further emission cuts. Regardless of how much priority society puts on the objective of maintaining a small-scale farm structure all over the country, subsidies need to be increased.

The results of this study are somewhat in contrast with the results found in the literature, in which a 30 per cent emission cut leads to a 23 per cent reduction in food production and land use [3,4]. These studies are not easily comparable because of the use of different models and scenarios. Nevertheless, the results reported in this paper show a weaker relationship between GHG emission cuts, production and land use. Agrispace allows for more input substitution than the models in [2], [3], and [4] in which production technology is mostly fixed. The approach taken in Agrispace seems more appropriate as it better captures farmers' responses to changes in relative prices. The results of this study are in line with Himics et al. [23] who study agriculture in the European Union. They report a reduction in GHG emissions by 21 per cent and a decline in land use by 5.6 per cent (including set aside and fallow land). This leads to a slight extensification in which more land is used to produce the same amount of food. It may be a feasible way to reconcile competing agricultural policy objectives of maintaining agriculture all over the country and achieving significant GHG emission cuts.

A major methodological improvement presented in this paper lies in the exploitation of the dynamic structure of the model to yield a path of GHG emissions between the base year and the simulation year. Comparative-static models simulate only the new equilibrium solution, but do not model the path of adjustment. Annual figures and the development path, however, are crucial for the economics of climate change and climate policies.

As is common in modelling, results do not come without caveats. While the results account for the parameterization of the model, and the substitution elasticities of inputs in particular, the results indicate relatively small, reasonable changes. It is also unclear whether the parameter values that are calibrated to mimic past structural change in agriculture, will be valid under the conditions described in the scenarios. Another caveat is the lack of explicit modelling of animals as inputs in the production function. This may be especially important when it comes to GHG emission accounting as animals present a large share of GHG emissions from agriculture. Moreover, payments made to animals must be linked to other inputs or outputs. Neither choice is completely satisfying, as farmers' responses to a change in animal payments cannot be addressed appropriately in the model. The caveats present important venues for future research.

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