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# The transition of agriculture to low carbon pathways with regional distributive impacts

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ABSTRACT

This study, based on agricultural sector modelling, shows how changes in food consumption and land use measures can reduce GHG emissions from Finnish agriculture, and what are the impacts on regional levels of agricultural production, land use, GHG emissions, and farm income. The results demonstrate that it is difficult to achieve a large reduction in GHG emissions from agriculture by just changing diet alone. There is a big disparity in the distribution of farm income among the main regions in Finland due to a radical decrease in the consumption of livestock products. However, land use measures alone do not create the disparity in farm income among the different regions. Combining changes in diet and land use is the most effective in mitigating GHG emissions from agriculture, but the relatively disadvantaged regions with high shares of livestock production and peatlands may experience major restructuring in agriculture and land use.

## 1. Introduction

The European Union (EU) aims to be carbon neutral by 2050. However, Finland has a more ambitious goal to become carbon neutral by 2035. This goal won't be achieved unless new actions to cut greenhouse gas (GHG) emissions are quickly introduced in all sectors. Rapid transition of the economy and society to a low carbon pathway in Finland requires also very significant reductions in agricultural GHG emissions, currently at 16 Mt $CO_2$ eq., including agricultural sector emissions, land use, land use change, & forestry (LULUCF) emissions and energy use emissions from agriculture as reported in the National GHG Inventory that are accounting to over one-fifth of the total GHG emissions in Finland (Statistics Finland, 2021a). Land use measures are prioritised in this study because 75% of GHG emissions from Finnish agriculture come from soils and more than 50% of the emissions are from peatlands (Statistics Finland, 2021a). In addition, measures such as climate friendly feed concentrates or manure spreading technologies, and biogas may very likely result in smaller reduction in emissions and are more expensive to implement compared to land use measures in the efforts to mitigate GHG emissions in Finland (Lehtonen et al., 2020, Maanavilja et al., 2021).

Koljonen et al. (2020) concluded that the pathway towards carbon neutrality in Finland has relatively small effects on the national economy in net terms, however, individual sectors of the economy may be significantly changed in terms of technology and volume of production. The socioeconomic consequences as well as fairness and acceptability issues of this transition in the different sectors and regions of Finland have been barely studied. Hardly any attention has been paid on the differences and disparities in terms of income and socio-economic developments between different regions in Finland. Lehtonen et al. (2020) constructed a roadmap for large reductions in GHG emissions from agriculture but did not evaluate the regional impacts on agricultural production, land use, GHG

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emissions, and farm income. Regional effects are important to be considered in the context of transitioning towards low-carbon food systems because agriculture and food sector is an important source of employment and income in some of the rural regions in Finland (Statistics Finland, 2021b).

There is a need for studies investigating how agriculture could reach sizable reductions in GHG emissions, what might be the production implications and socioeconomic consequences, and how large might be the differences in the impacts between the agricultural production lines and regions. This study, based on agricultural sector modelling, aims to show how changes in food consumption and specific land use measures can reduce GHG emissions from Finnish agriculture, and what are the likely impacts on regional levels of agricultural production, land use, GHG emissions, and farm income. Then the economic consequences and socioeconomic disparities between the different regions in Finland can be analysed.

While the challenges in GHG reductions can be considerable from the technical and production point of view, the socioeconomic implications can be significant and vary from region to region. In Finland, especially in the case of peatlands that produce almost 60% of the total GHG emissions from agriculture but comprise only 11% of the total cultivated land (Kekkonen et al., 2019). There are abundant cultivated peatlands in the northern regions and coastal areas in the middle parts of Finland, where the share of livestock production is also high and of great socioeconomic importance.

The sector modelling results derived in this study are used to evaluate how the transition to a low carbon food system may develop and how it could be promoted in a just manner. McCauley and Heffron (2018) defined “just transition” as “a fair and equitable process of moving towards a post-carbon society” and stated that the urgency of carbon reduction necessitates a united conceptual approach to guarantee justice throughout this transition. This transition is reshaping our environment and ecosystems as well as the climate of the future. Food and agricultural practices are entangled in multiple structural processes (political, economic, social, and cultural) in different interlinked domains (regional, national, international).

Research on low-carbon just transition has mainly concentrated on energy systems (McCauley and Heffron, 2018; Sovacool et al., 2019), but recently the issue of just transition has also attracted considerable interest in food systems research (Gilson and Kenehan, 2019; Tribaldos and Kortetmäki, 2022). The distributive justice dimension focuses on examining who benefits and who suffers from the transition, and in what ways (Newell and Mulvaney, 2013), as well as clarifying the kind of variations in distribution that matter to considerations of justice. Procedural justice, in turn, draws attention to fairness and participation in decision-making and policy processes (Williams and Doyon, 2019). Concerning intergenerational justice, present generations have certain duties towards future generations – climate change raises particularly pressing issues on how available natural resources can be used without threatening the sustainable functioning of the planet’s ecosystems and the rights of future generations as well as how to balance the rights’ claims of existing generations against the rights’ claims of future generations Page (1999).

Dominant food and agricultural practices have a significant impact on the environment and contribute to climate change to the extent that they are systemic rather than localised – the harms that amount to structural injustices are the consequences of the system-wide processes and structures where food is produced, distributed, marketed, accessed, eaten, and regulated (Gilson and Kenehan, 2019). An example of structural injustices is that most of the farmlands with organic soils currently in agricultural use have been cleared by and inherited from previous generations. In order to improve food security, there was a need to clear land (including peatlands) to establish new fields after Finland became independent in 1917 as well as the experiences of food shortages during the Second World War. This also led to governmental support for land clearance especially during the 1950s and a significant increase in the cultivation of peatlands. As several generations have benefited from the land clearance, it would be unfair to demand that the current generation of farmers to rapidly reduce GHG emissions from agricultural peatlands without societal assistance. Therefore, the conflicting aims and values between promoting food security and preserving ecological resilience should be addressed Noll (2019).

In this study, the simulation results derived from economic sector modelling are analysed and discussed from the just transition and fairness point of view. Distributive justice is dealing with how fair is the outcome in changing land-use for agriculture and how the low carbon pathways will affect the distribution of farm income regionally. We pay attention, in particular, to the distributive effects of different pathways in four main agricultural regions, since production conditions (e.g., topography, soil types, effective temperature sum over the growing season), structure of production, as well as the economic and societal role of agriculture are varied across different regions in Finland. Procedural justice is dealing with how the policy towards better management of peatlands is transparent and how to develop participative processes to make the transition fair, for example, by giving farmers a voice and an opportunity to choose the appropriate policy solutions for shifting agricultural production from peatlands to mineral soils in Finland. Therefore, in-depth knowledge from research studies may help in intergenerational justice in the transition towards low carbon pathways because fully informed farmers may agree to assume disproportional burdens due to the possibilities of other opportunities in the pursuit to tackle climate change. Instead of passing the high costs to future generations, the current generation of farmers can reduce GHG emissions from agricultural peatlands at certain bearable costs and thus circumvent the grave consequences of climate change in the future.

This study proceeds in the following order. The main characteristics of the agricultural sector model as well as the scenarios on the per capita changes in diet and land use policy measures are presented in the materials and methods section. Results for the simulated agricultural production, land use, farm income, and GHG emissions at the whole country level and in the four main regions of Finland are presented according to the changes in diet and land use policy scenarios. The implications of the modelling results in relation to distributive justice (e.g., fair income distribution) and procedural justice (e.g., fair decision-making processes) along with intergenerational justice (e.g., act now for future generations) are analysed in the discussion. The main findings and justice issues for the transition of the food system in Finland are summarised in the conclusions.

## 2. Materials and methods

### 2.1. Sector model and its regional disaggregation

The agricultural sector model Dremfia (Lehtonen, 2001) was used in simulating the agricultural production, land use, GHG emissions, and farm income for different scenarios with extension made to the model to examine the use of peatlands. The model considers demand of agricultural products, EU level prices of agricultural inputs and outputs, and agricultural policy. The model is a recursive-dynamic model, with a market model producing annual level results on the consumption of domestic and imported agricultural commodities, the exports, agricultural production with animal and crop production and land use specific variables from 1995–2050. Investments, production capital depreciations, changes in (past and future) input and output prices and agricultural policy as well as possible food demand and crop productivity changes are determined in the recursive-dynamic setting (Lehtonen 2001, 2004; Lehtonen and Niemi, 2018). The model outcomes include total farm income and labour use in agriculture.

Four main areas are included in the model: Southern Finland, Middle Finland, Ostrobothnia (the western part of Finland) and Northern Finland (Fig. 1). Food consumption and market balance equations (supply equals demand) are specified per each main region, but agricultural commodities may be transported between the main regions. Exports and imports are assumed to take place through Southern Finland (sea traffic connections). The annual level market model is a typical spatial price equilibrium model based on optimisation (e.g., Cox and Chavas, 2001), except that no explicit supply functions are specified, i.e., supply is a primal specification. Imported and domestic products are imperfect substitutes. Exogenous EU prices drive domestic prices, which may be slightly different from EU prices, depending on the balance between supply and demand in domestic markets.

While changes in total demand per capita of different food products over time is driven by exogenous demand trends in the model, the model is free to decide the level of domestic production in all regions, and imports and exports at the whole country level. The demand system in the model is based on Armington-assumption (commonly used in agricultural sector models and general equilibrium models) which considers domestic and foreign products as more or less imperfect substitutes Lehtonen (2001). The parameters of the demand system include price elasticity of demand and substitution elasticity between domestic and imported products. The substitution elasticities have been adjusted in the model calibration so that the domestic prices, dependent on exogenous EU price level in the model and the domestic consumption of domestic and imported foods, are very close to the observed statistical values from 1995-2020, especially in the most recent years. Hence, the future food demand scenarios, assumed to be driven by consumers' values and preferences, are given as exogenous parameters to the model for evaluating the effects on national and regional production, land use and GHG emissions Lehtonen (2012).

Production in the four main regions is further divided into sub-regions based on the support areas. In total, there are 17 different production regions (not all small regions are visible in Fig. 1). This allows a regionally disaggregated description of policy measures, crop yields and production technology. Almost all pork, poultry meat and specialised crop production is concentrated in Southern

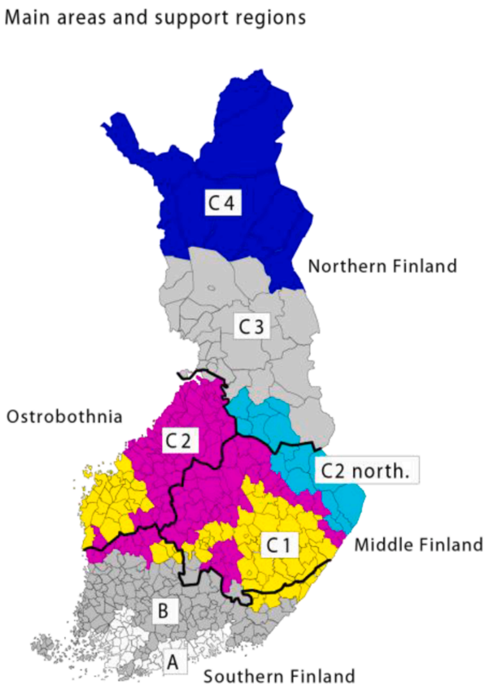


**Fig. 1.** Regional disaggregation of the DREMFIA sector model. White: support zone A; Dark Grey: support zone B; Yellow: support zone C1; Pink: support zone C2; Light Blue: support zone C2 northern; Light Grey: support zone C3; Dark Blue: support zone C4.

Finland and Ostrobothnia region. Only 20% of milk and beef are currently produced in Southern Finland where approximately 50% of farmland is located, meanwhile dairy and beef and related feed crop production dominate agriculture in Middle and Northern Finland. The DREMFIA model includes the following production activities per region: the number of different animals, hectares under different crops, set-aside, feed diets of animals, chemical and manure fertiliser use per crop, and resulting crop yields. The model excludes horticulture, lambs, reindeers, horses, and fur animals which are minor in terms of GHG emissions.

The greenhouse gas calculation in the Dremfia sector model follows the principles and parameters of the National GHG Inventory practices (Statistics Finland, 2021a; Lehtonen, 2012). Dremfia calculates more than 95% of the $CO_2$-equivalent GHG emissions reported in Finland (Statistics Finland, 2021a). Less chemical nitrogen fertiliser is needed when cultivating any crop on peatlands, compared to cultivation activities on mineral soils. It is assumed that 25 kgN/ha less chemical nitrogen is needed in cultivating on peatlands than on mineral soils. However, crop yields are slightly (1–7%) reduced on peatlands, due to low soil pH values, compared to the yield levels from mineral soils (Purola and Lehtonen, 2021). It is also assumed that there is a larger reduction in cereals yields (5–7%) compared to grassland yields (1—4%) on cultivated peatland due to low soil pH values. This assumption, which is well in line with the literature and opinions of crop experts, implies that approximately 35% of peatlands are allocated to cereals in 2018-2020 in the model solution, and this is very close to the observed cultivation in 2018.

All cropping activities are defined separately for mineral soils and peatlands in the model. This is a new feature of the model created specifically for this study. While the average share of peatlands is around 11% (260,000 ha) out of all utilised agricultural land in Finland, they are relatively more abundant in the Ostrobothnia region (where appr. 20% of all farmlands is peatland) and Northern Finland (40% peatlands), and relatively scarce in Southern Finland where the share of peatlands is around 4% only. The share of peatlands is appr. 10% in the middle and eastern parts of the country. About 50% of all cultivated agricultural land is located in Southern Finland, 26% in Ostrobothnia, 18% in Middle Finland, and more than 5% in Northern Finland. Concerning the unequal distribution of different soils and availability of agricultural land, Ostrobothnia has proportionally much more cultivated peatlands compared to Southern Finland. Furthermore, the agri-food sector (including both agriculture and food industry) is important in Ostrobothnia and consisting of 11.2% of the region's value added and 9.8% of the region's employed labour force, followed by Middle Finland (8.5% and 7.3%) and Northern Finland (5.2% and 5.7%), in comparison to the country's average of 4.9% of national value added and 4.7% of the Finnish labour force in 2020 (Statistics Finland, 2021b).

The validation of the overall model is a multi-phase process and based on statistical data, input use data from a "typical farm" along with expert judgement (Lehtonen 2001, 2004; Lehtonen and Niemi, 2018). First, given EU level prices, observed domestic prices, and realised import volumes, the substitution elasticities of the Armington-based demand system in the model are adjusted to reach observed prices and import volumes. Second, the parameters of specific investment models for dairy farm size are adjusted in order to replicate the observed evolution of dairy farm size structure from 1995-2019. Third, milk yield function of dairy cows is checked and validated in order to replicate the realised milk yields of dairy cows. Fertiliser use and crop yields have been validated using empirically estimated crop yield response functions and statistics of regional crop yields, fertiliser use as well as prices of crops and fertilisers at the national level. Fourth, some residual costs of different cropping activities have been adjusted to reach the observed overall land use and production levels. The validation of the model leads to the observed land use and production levels. More emphasis has been given on validating the model to match the statistical data from recent years.

### *2.2. The scenarios*

To be able to analyse the changes in diet and effects of policy interventions on land use, we first specify three alternative scenarios based on different assumptions of two key drivers, food consumption (Table 1: Description of diet) and agricultural policy (Table 1: Description of agricultural policy). The specified scenarios include a reference diet based on current food consumption and two alternative diets with reduced levels of meat and dairy products consumption that comply with the national nutritional recommendations (National Nutrition Council, 2014) so that the nutritional intake is not compromised. These three scenarios interact then with three alternative options on land use policy intervention by utilising soil emission abatement subsidy to reduce GHG emissions from land use. The combination of three diet scenarios and three soil abatement subsidy options gives a total of 9 scenarios (Table 1).

All the scenarios share the same population and price projections to facilitate cross-scenario comparisons. Population development

**Table 1**
Summary of the 9 scenarios projected to 2050. SEAS = Soil emission abatement subsidy.

| Scenario name | Description of diet | Description of agricultural policy | Description of land use policy intervention options |
|---|---|---|---|
| Baseline scenario (BAU) | 2020 baseline diet projected to 2050 with no changes in per capita consumption | Coupled subsidies for bovine animals and milk, and per hectare payments will remained unchanged | 1 No intervention<br>2 SEAS = €10/t$CO_2$eq<br>3 SEAS = €20/t$CO_2$eq |
| Small diet change scenario (SDC) | Per capita consumption of meat and dairy products is assumed to decrease by 1/3 by 2050 | Coupled subsidies for livestock production are reduced by 10%, and the less favoured area payment by 30% | 4 No intervention<br>5 SEAS = €10/t$CO_2$eq<br>6 SEAS = €20/t$CO_2$eq |
| Large diet change scenario (LDC) | Per capita consumption of meat and dairy products is assumed to decrease by 2/3 by 2050 | The coupled subsidies for livestock production are reduced by 20% and the less favoured area payment by 50% | 7 No intervention<br>8 SEAS = €10/t$CO_2$eq<br>9 SEAS = €20/t$CO_2$eq |

is based on Statistics Finland's (2019) latest population projection, showing a slightly growing population until 2030, but a slowly declining population steadily after that. The population in 2050 will be roughly 100,000 less than the current 5.5 million. Future prices of agricultural outputs and inputs are assumed to follow price development projected by OECD-FAO (2020) agricultural outlook 2020-2029. Global supply growth is expected to outpace demand growth over the next ten years, causing real prices of most agricultural products to remain at or below their current levels in the world markets.

#### *2.2.1. Baseline scenario*

The baseline scenario is characterized by a continuation of current diet and current (2020–2021) agricultural policy. Baseline shows how Finnish agriculture would look like should climate mitigation remain a relatively minor aim for food and agricultural systems. Consumers in Finland are assumed to maintain their preferences for GHG-intensive food, including livestock products. The scenario also corresponds to the continuation of the current 2014–2021 agricultural policy over the study period, up to 2050. The coupled subsidies for bovine animals and milk, which are of great importance especially in Northern Finland, will be maintained at the current level. High per hectare payments, paid irrespective of the soil type and GHG emissions, will also remained unchanged.

#### *2.2.2. Small diet change scenario*

The second scenario is called "small diet change scenario" (SDC). Under this scenario, consumption of meat and dairy products is assumed to decrease by 1/3 (33%), while consumption of pulses, bread cereals and fish gradually increase significantly by 2050. The changes in diet have been implemented in the DREMFIA model as an exogenous shift of demand functions per capita because of changing consumer preferences and support from public policy measures such as dietary recommendations. We do not assume any changes in food taxes or other similar economic instruments. It is assumed that an equal reduction will take place in meat products across all livestock (beef, pork, and poultry) and across different animal parts. Substitutions in consumption are based on fish and plant-based foods such as grain legumes, full grain cereals, vegetables, and imported plant-protein sources that are complying with the Finnish nutritional recommendations (National Nutrition Council, 2014). Hence, the changes in diet have sufficient energy and protein intake. In order for domestic agricultural production to respond to the changes in consumption and to avoid an increase in exports through the aid of farm subsidies, agricultural support policy is also changed by reducing the coupled subsidies for livestock production by 10% and the less favoured area payments by 30% (Table 1).

#### *2.2.3. Large diet change scenario*

The third scenario is called the "large diet change" scenario (LDC). It describes a future, in which diets have shifted towards a significantly lower consumption of livestock products (implemented exogenously) and a higher intake of plant-based products due to a rising consumer awareness regarding sustainability issues. Under this scenario, the consumption of meat and dairy products is assumed to decrease by 2/3 (67%), while the consumption of plant-based proteins will increase substantially by 2050. This large reduction in animal-based proteins is possible because of a larger increase in the substitutions, compared to the SDC scenario. Energy and protein content in the diet is little affected by the large reduction of meat and dairy products, since plant-based foods with similar nutrients are increased, as well as fish consumption. In the same way as the SDC, an equal reduction will take place in meat products across the main livestock species, and agricultural policy will be changed accordingly to meet the changing demand for food by reducing subsidies for livestock production as well as per hectare subsidies. The coupled subsidies for livestock production are reduced by 20% and the less

**Table 2**
Soil emissions ($tCO_2eq$) per ha on mineral and peat soils.

| | **GHG emissions $tCO_2eq$/ha per year*** | | | |
|---|---|---|---|---|
| Land use option | Mineral soil – GHG coefficient used in soil emission abatement subsidy calculation | Organic soil | Abandoned land on organic soils | Organic soil – GHG coefficient used in soil abatement subsidy calculation |
| Spring wheat | 2.0 | 35.1 | 15.5 | 19.6 |
| Winter wheat | 2.0 | 35.1 | 15.5 | 19.6 |
| Feed barley | 2.0 | 35.1 | 15.5 | 19.6 |
| Malting barley | 2.0 | 35.1 | 15.5 | 19.6 |
| Oats | 2.0 | 35.1 | 15.5 | 19.6 |
| Oilseed rape | 2.0 | 35.1 | 15.5 | 19.6 |
| Grass | 1.0 | 25.3 | 15.5 | 9.8 |
| Set-aside | 1.0 | 25.3 | 15.5 | 9.8 |

* *The coefficients at the furthest right side are authors' calculations, while the other emissions factors on peatlands are the same as those used in national GHG inventory of Finland (IPCC, 2014). The coefficients used for mineral soils, rounded up to the closest integer values by authors, include also the $N_2O$ emissions from fertilisation, and they are also used in Purola and Lehtonen (2021).*

favoured area payments by 50% (Table 1).

#### 2.2.4. Scenarios for soil emission abatement subsidy in different levels

Soil emission abatement subsidy (SEAS) is a policy intervention which can provide an incentive to reduce all GHG emissions from agricultural soils. Agricultural soils emit mainly $CO_2$ and $N_2O$. Both gases are considered in the soil emission abatement subsidy as implemented in the following text.

Soil emission abatement subsidy incentivises through a premium payment for reducing emissions from the historical level of soil emissions, e.g., 2020. A farm cannot affect past emissions, but only current and future emissions.

Premium payment for a farmer: premium payment*(past emissions - current emissions) = premium payment*past emissions – premium payment*current emissions where premium payment is the payment, €/t $CO_2$eq, for a farmer; past emissions is the GHG emission of a farm in a chosen base year (e.g., 2020), which a farmer cannot affect. The first term does not affect current production decisions of a risk neutral farmer, but only his/her income levels. However, farmers can influence current and future emissions.

Assume that a farmer is first paid at the beginning of each year a premium payment by the government based on the historical GHG emissions at the base year. A farmer cannot influence this payment, but a farmer must pay back the government the value of current emissions at the end of the year. Hence, a farmer has an incentive to decrease current emissions. This incentive is the premium payment in the second term. Hence, the premium payment works effectively as a soil emission tax, thus influencing production at the farm level and soil emissions from the farm.

The levels of the soil emission abatement subsidy considered in this study are the following: 10 and 20 €/t$CO_2$eq. The soil emission abatement subsidy rates per ha are determined based on the following GHG emissions coefficients which include both $CO_2$ and $N_2O$ emissions from mineral and organic soils (Table 2). However, a farmer may also abandon the peatland instead of producing any crop or allocating land to set aside. Then the emissions from organic soils are still as high as 15.5 t$CO_2$eq/ha per year.

We do not consider other land use options in this study, such as rewetting peatlands, due to the lack of data on costs. In other words, we assume that a farmer cannot perform better in terms of GHG reductions than abandoning the peatlands. If more data is available on the costs of rewetting peatlands used in agriculture and knowledge of the potential in rewetted area, rewetting peatlands may be an avenue for future analysis.

Based on the coefficients at the right side of Table 2, there are the following potential economic gains for farmers if land use changes on peatlands. If SEAS=€10/t$CO_2$eq and 1 ha of peatlands under annual crops are converted to perennial crops such as grasslands or 1 ha of peatlands under grasslands are abandoned with GHG abatement of 9.8 t$CO_2$eq/ha per year, a farmer would gain (if not considering the economic costs of foregone revenues) about €100/ha [coefficient 9.8 x €10]. If SEAS=€10/t$CO_2$eq and 1 ha of peatlands under annual crops are abandoned with GHG abatement of 19.6 tCO2eq/ha per year, a farmer would gain about €200/ha [coefficient 19.6 x €10]. However, the net economic gain would be smaller since the economic returns, considering both revenues and costs, would most likely be decreased. Different emission abatement subsidy levels imply varying annual lump-sum payments (input for the *DREMFIA* sector model) for farmers in the different regions and whole country as presented in Table 3.

## 3. Theory

The underlying hypothesis in the DREMFIA sector model is competitive markets: Producers engage in profit maximising behaviour and consumers engage in utility maximising behaviour. Decreasing marginal utility of consumers and increasing marginal cost per unit produced in terms of quantity lead to equilibrium market prices that are equal to the marginal cost of production in competitive markets. Each region specialises in products and production lines that yield the greatest relative profitability, taking into account the profitability of production in other regions and consumer demand. This means that total use of different production resources, including farmland, in different regions is optimised in order to maximise sectoral welfare, considering differences in resource quality, technology, costs of production inputs and transportation costs.

The Dremfia model consists of two main parts: an optimisation routine simulating annual production decisions (within the limits of fixed factors) and price changes, i.e., supply and demand reactions, by maximising producer and consumer surplus subject to regional product balance and resource (land and capital) constraints along with a technology diffusion model that determines sector-level investments in different production technologies in different farm size categories.

Investments in different dairy farm size categories are modelled using a framework of technology diffusion in a recursive-dynamic model (Lehtonen, 2001, 2004). It means that farm size growth and technical change of dairy production is endogenous in the model: the input use and costs per cow are different in four different farm size categories (less than 20 cows, 20–49 cows, 50–99 cows, and 100 and more cows). Investments have been increasingly concentrating on larger farms but not immediately since the largest farm size

**Table 3**
Paid annual total compensation (€ million) at different rates of soil emission abatement subsidy (SEAS)*

| SEAS €/t$CO_2$eq | Southern Finland | Middle Finland | Ostrobothnia | Northern Finland | Whole country |
|---|---|---|---|---|---|
| 10 | 23,2 | 10,0 | 20,5 | 5,8 | 59,5 |
| 20 | 46,4 | 19,9 | 41,0 | 11,6 | 118,9 |

* *SEAS is calculated based on land use variables from the DREMFIA sector model in 2020. Regional disaggregation: See Fig. 1. Note: Farmers have to pay back 100% if emissions are unchanged, 90% if they reduce emissions by 10%, 80% if they reduce emissions by 20%, etc.*

categories are not equally accessible for smaller farms and hence, they invested in middle sized farms (20–49 cows) before 2010, but after that almost all investments have been made at farm types with more than 50 cows. The increase of average dairy farm size increases labour productivity and the relative share of capital needed, thus the production cost per litre of milk decreases. The modelled ex post farm size distribution is validated based on official farm size statistics (see e.g., Lehtonen and Niemi, 2018). This modelling of specific investment for farm size is crucial because (1) milk and related beef production (where farm size has rapidly increased since 1995) contributes to about half of Finnish agricultural income, and it affects land use especially in Middle and Northern Finland where peatlands are abundant, (2) in the different scenarios, the investment model allows re-allocation of production to the most feasible and relatively competitive regions and sub-regions as well as incentivise production shifts to regions with abundant mineral soils. The specific investment models for dairy farm size are coupled to land availability and land price in the regions since the marginal value of land (derived from the market model at annual level) is used as a cost in the investment model.

## 4. Results

### *4.1. Agricultural production with scenarios for changes in diet*

The results from the sector model simulations suggest that livestock production follows closely the domestic demand of livestock products in the alternative diet scenarios. This is because the prices of OECD-FAO (2020) assumed for exogenous EU prices in the baseline and all scenarios remain almost unchanged in real terms, considering the increased prices of inputs such as energy and fertilisers. Production linked subsidies are decreased in the diet scenarios, and this ensures that exports of agricultural products do not increase as a result of declining consumption to avoid emissions leakage. Hence, livestock production (dairy, beef, pork, poultry) and the related import volumes follow quite closely the changes in domestic demand in the scenarios. Dairy production decreases by 36% in the SDC scenario (1/3 reduction in the consumption of livestock products) and 65% in the LDC scenario (2/3 reduction in the consumption of livestock products). In Middle Finland and Northern Finland, where production linked payments are reduced, milk production decreases by 68-70% in the LDC scenario, whereby these regions may face unequal burden due to the changes in diet. Beef production decreases by 19% already in the baseline scenario (no change in consumption) because of decreasing number of dairy cows due to increasing milk yield per cow and reduction in the number of dairy bred bulls. However, beef production largely follows the domestic consumption in the SDC and LDC scenarios. Pork and poultry production follow domestic consumption in all scenarios.

Since more than 70% of farmland in Finland is used for producing feed for animals, the need for utilised agricultural land decreases significantly in the SDC and LDC scenarios because of decreasing livestock production (Fig. 2). In the SDC scenario, about 470,000 ha, or 20% of arable land is freed up, but only 13,000 ha or 6% of organic soils is freed up. In the LDC scenario, more than a third (770,000

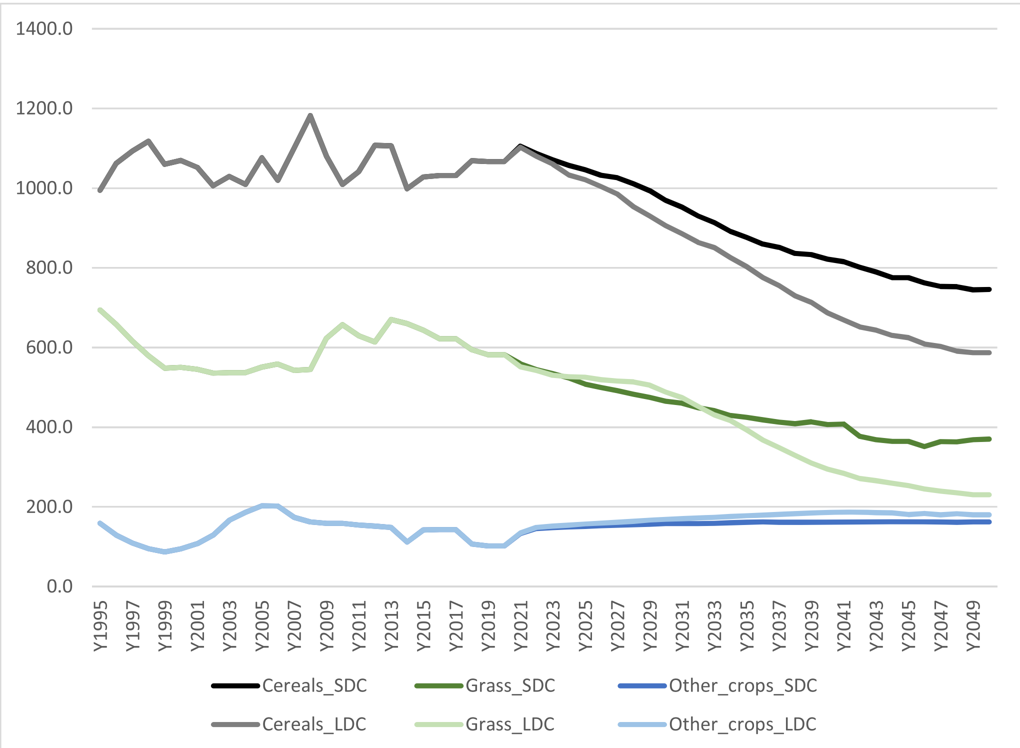


**Fig. 2.** Agricultural land use (1000 ha) in Finland in SDC and LDC scenarios. Source: DREMFIA sector model results.

ha) of arable land would be released from agricultural use, including more than 63,000 ha or 25% of peatlands is released from agriculture. There is more efficient use of farmland in Finland by reducing the consumption of livestock products because less farmland is needed to produce animal feed. Instead, arable land would be used to produce plant-based food directly for human consumption.

The increase in consumption of grain legumes for human consumption would replace the demand for grain legumes to feed livestock in the SDC and LDC scenarios. However, the increased consumption of grain legumes for plant-based food in the SDC and LDC scenarios only slightly increases the land-use area of "other crops" (including grain legumes, sugar beets, potatoes, oilseeds). Furthermore, the increased use of whole-grain cereals for food is also much less, in terms of production volume and area, than the decrease in the use of feed grain in the SDC and LDC scenarios.

What is significant, however, is an increase in cereal production on remaining peatlands as a result of declining livestock production. As the need for grass fodder production decreases and there are few feasible crops on peatlands in addition to forage grasses and cereals, peatlands are increasingly used for growing cereals in areas where peatlands have a high share of total agricultural land area. This is explained by the current EU Common Agricultural Policy (CAP) subsidy regime (2014–2021), which maintains peatlands in production and pays full subsidies for cereal production (annual crops) on peatlands that is causing significantly higher GHG emissions compared to grasslands (perennial crops) or cultivation on mineral soils (see Table 2).

### 4.2. Land use in agricultural production with scenarios for soil emission abatement subsidy

Introducing soil emission abatement subsidies (SEAS) have little effect on livestock production according to the model results up to 2050 because the sector model finds easily land for livestock activities that are producing the high value added per hectare for the farm in the long run. This is because there are abundant of mineral soils that have not been fully utilised in agricultural production and set aside areas that have varied between 200,000 – 300,000 ha since 2000.

However, cereals production is slightly reduced by 5–10% from the baseline levels, thus eliminating most of the feed cereals exports still prevalent in 2020, if soil emission abatement subsidy is introduced. This is because mineral soils are primarily used for livestock activities (forage grasslands) and some higher valued crops such as sugar beet, potatoes, malting barley, bread cereals, oilseeds. Hence, the soil emission abatement subsidy provides more value than feed cereal production on peatlands, therefore leading to the abandonment of agricultural peatlands.

The results suggest that implementing SEAS at the level of €10/t$CO_2$eq in the baseline would decrease peatland use in agriculture by almost 80% (Table 4). Furthermore, soil emission abatement subsidy effectively drives cereals production away from peatlands to mineral soils. Since most of the land in all regions is made of mineral soils, it is possible to find mineral soils for cereals production already in the baseline. If the demand for livestock products is reduced, it is easy to shift cereals production from peatlands to mineral soils. Therefore, low levels of soil emission abatement subsidy would incentivise abandoning of peatlands in the long run (up to 2050) and give priority to mineral soils.

However, in Northern Finland grasslands shift to mineral soils more sluggishly in the baseline. This is explained by the smaller share of mineral soils (60-70%) compared to the other regions and production incentive from the national payments of per litre of milk subsidy and per head of bovine animal subsidy in Northern Finland. Regarding the SDC or LDC scenarios, the SEAS=€10/t$CO_2$eq is sufficient to drive all cereals and almost all grassland areas from peatlands to mineral soils, and thus the abandonment of peatlands.

### 4.3. Agricultural GHG emissions with scenarios for soil emission abatement subsidy

What is significant in terms of GHG emissions in the SDC and LDC scenarios is that most land not needed in agricultural production remains as set aside land because of farm subsidies. Even if less favoured area payments are decreased in the scenarios, the overall subsidy level is still high enough to keep most of the peatlands in agricultural use despite significantly reduced demand for feed crops (grass forage and feed cereals oats and barley). Out of 260 000 ha peatlands used in agriculture, only 13,000 ha of peatlands are abandoned in the SDC scenario, and 63,000 ha of peatlands are abandoned in the LDC scenario (Table 4).

Nevertheless, the modelling results show that already low levels of soil emission abatement subsidy are sufficient to significantly

**Table 4**
Peatland areas (1000 ha) freed up from agricultural production in 2050. SEAS = Soil emission abatement subsidy.

| | Southern Finland | Middle Finland | Ostrobothnia | Northern Finland | Whole country |
|---|---|---|---|---|---|
| Peatlands cultivated in 2020 | 51.9 | 43.0 | 107.1 | 54.2 | 256.2 |
| **BASELINE in 2050** | | | | | |
| SEAS €0/t$CO_2$eq | 0.1 | 0.0 | 0.0 | 5.8 | 5.9 |
| SEAS €10/t$CO_2$eq | 42.6 | 43.0 | 107.1 | 11.7 | 204.4 |
| SEAS €20/t$CO_2$eq | 51.9 | 43.0 | 107.1 | 36.5 | 238.5 |
| **SMALL DIET CHANGE (SDC) SCENARIO in 2050** | | | | | |
| SEAS €0/t$CO_2$eq | 0.1 | 3.2 | 0.0 | 9.5 | 12.9 |
| SEAS €10/t$CO_2$eq | 45.9 | 43.0 | 107.1 | 48.8 | 244.8 |
| SEAS €20/t$CO_2$eq | 51.9 | 43.0 | 107.1 | 54.2 | 256.2 |
| **LARGE DIET CHANGE (LDC) SCENARIO in 2050** | | | | | |
| SEAS €0/t$CO_2$eq | 0.1 | 9.3 | 8.7 | 45.3 | 63.3 |
| SEAS €10/t$CO_2$eq | 51.6 | 43.0 | 107.1 | 53.8 | 255.5 |
| SEAS €20/t$CO_2$eq | 51.9 | 43.0 | 107.1 | 54.2 | 256.2 |

reduce the use of peatlands and GHG emissions from agriculture. Thus, the results demonstrate how important it is to include specific land use measures in mitigating GHG emissions from agriculture. Already in the baseline scenario without changes in diet, the soil emission abatement subsidy payments would lead to large reductions in GHG emissions from agriculture. Even at the level of €10/ $tCO_2eq$ in the baseline, agricultural GHG emissions would decrease by over 5 Mt $CO_2eq$ per year in 2050 (Table 5). Land use measures are vital in reducing GHG emissions from agriculture since the diet change scenarios without specific land use measures would only contribute GHG reductions of 1.3 Mt $CO_2eq$ for the SDC scenario and 1.5 Mt$CO_2eq$ for the LDC scenario (Table 5). The reason is a high share of peatlands still used for cereals production, therefore resulting in a very high level of per hectare GHG emissions. Consequently, changes in diet alone would not be effective in reducing GHG emissions from agriculture without incentives to reduce peatland from agricultural use. Finally, the combination of changes in diet and land use would produce the largest abatement in GHG emissions. Only at the level of €10/$tCO_2eq$, agricultural GHG emissions would decrease by 7 Mt $CO_2eq$ per year for the SDC scenario and 8.5 Mt $CO_2eq$ per year for the LDC scenario (Table 5). Therefore, the modelling results show the advantages in exploiting land use measures targeted at cultivated peatlands to considerably reduce GHG emissions from agriculture.

### *4.4. Development of farm income with scenarios for soil emission abatement subsidy*

In the baseline, total farm income decreases by 11% in 2050 when assuming the OECD-FAO 2020 prices of agricultural products and inputs up to 2029 and keeping them fixed from 2030 onwards. This decrease in total farm income is mainly because of decreasing beef production by around 20% due to decreasing number of dairy cows and increasing milk yield per cow and 4% reduction in the total milk production volume. Reduction of almost 10% in the total cereals production also contributes to the slow and gradual decrease in total farm income. Therefore, the modelling results estimated a drop in farm income even without any changes in diet or land use. This is an indication of a decreasing trend in Finnish farm income.

In the baseline scenario, total farm income would increase in 2050 if €10 to €20/$tCO_2eq$ of SEAS is paid to farmers (Table 6). However, in the SDC scenario without SEAS payments, total farm income decreases moderately on average in Finland and in Ostrobothnia, but significantly in Northern Finland and Middle Finland. The unequal burden faced by Northern Finland and Middle Finland is due to the dependency of farm income on livestock production (dairy and beef). The increase in legumes and bread cereals production in Southern Finland and southern part of Ostrobothnia would partly compensate for the decreased value in livestock production, hence the moderate decrease in farm income for Ostrobothnia. In contrast, total farm income in the SDC scenario may be higher for Southern Finland, sustained close to the levels of the “baseline without diet change” scenario for Ostrobothnia, and moderate decrease for Northern Finland and Middle Finland, if €20/$tCO_2eq$ of SEAS is paid to farmers (Table 6).

Compared to the LDC scenario, farm income would drop significantly and quite drastically in Northern Finland and Middle Finland, but somewhat less in Ostrobothnia and Southern Finland because specialised crop production activities might compensate part of the lost farm income. If €20/$tCO_2eq$ of SEAS is paid to farmers, total farm income may be higher for Southern Finland compared to the levels of the “baseline without diet change” scenario and moderate decrease for Ostrobothnia, however, total farm income in Northern Finland and Middle Finland are still seriously affected by the huge decrease in livestock production (Table 6). Therefore, a vast reduction in the consumption of livestock products in Finland would create unfairness in the regional distribution of farm income.

## 5. Discussion

### *5.1. Limitations of this study*

In this study, gradual changes in consumer preferences are assumed to be the main driver of changes in diet. However, this study did not evaluate how the consumption of meat and dairy products could be reduced by 1/3 or 2/3 because changes in diet have been

**Table 5**
Total GHG emissions (in Mt $CO_2eq$) from Finnish agriculture in 2050. SEAS = Soil emission abatement subsidy.

| | Southern Finland | Middle Finland | Ostrobothnia | Northern Finland | Whole country | Change 2050/ 2020 |
|---|---|---|---|---|---|---|
| Total emissions in 2020 | 4.9 | 2.7 | 5.5 | 1.7 | 14.9 | |
| **BASELINE in 2050** | | | | | | |
| SEAS €0/$tCO_2eq$ | 4.2 | 3.4 | 4.4 | 1.7 | 13.6 | -0.5 |
| SEAS €10/$tCO_2eq$ | 3.0 | 1.8 | 3.3 | 1.5 | 9.6 | -5.3 |
| SEAS €20/$tCO_2eq$ | 2.9 | 1.9 | 3.3 | 1.3 | 9.3 | -5.6 |
| **SMALL DIET CHANGE (SDC) SCENARIO in 2050** | | | | | | |
| SEAS €0/$tCO_2eq$ | 4.2 | 2.8 | 4.3 | 2.2 | 13.5 | -1.3 |
| SEAS €10/$tCO_2eq$ | 2.6 | 1.4 | 2.9 | 1.0 | 7.9 | -7.0 |
| SEAS €20/$tCO_2eq$ | 2.5 | 1.4 | 2.8 | 0.9 | 7.7 | -7.2 |
| **LARGE DIET CHANGE (LDC) SCENARIO in 2050** | | | | | | |
| SEAS €0/$tCO_2eq$ | 4.4 | 2.4 | 5.4 | 1.1 | 13.4 | -1.5 |
| SEAS €10/$tCO_2eq$ | 2.2 | 1.1 | 2.3 | 0.8 | 6.4 | -8.5 |
| SEAS €20/$tCO_2eq$ | 2.2 | 1.1 | 2.3 | 0.8 | 6.4 | -8.5 |

**Table 6**
Farm income (€ million) in 2050. SEAS= Soil emission abatement subsidy.

| | Southern Finland | Middle Finland | Ostrobothnia | Northern Finland | Whole country | Difference to SEAS 0 |
|---|---|---|---|---|---|---|
| Farm income in 2020 | 286.1 | 179.7 | 259.7 | 66.6 | 792.2 | |
| **BASELINE in 2050** | | | | | | |
| SEAS €0/t$CO_2$eq | 247.1 | 155.4 | 247.0 | 58.2 | 707.7 | |
| **2050/2020, share** | **0.86** | **0.86** | **0.95** | **0.87** | **0.89** | |
| SEAS €10/t$CO_2$eq | 253.1 | 166.8 | 242.0 | 60.2 | 722.2 | 14.5 |
| **2050/2020, share** | **0.88** | **0.93** | **0.93** | **0.90** | **0.91** | |
| SEAS €20/t$CO_2$eq | 259.1 | 173.1 | 257.0 | 66.2 | 755.4 | 47.8 |
| **2050/2020, share** | **0.91** | **0.96** | **0.99** | **0.99** | **0.95** | |
| **SMALL DIET CHANGE SCENARIO (SDC) in 2050** | | | | | | **Difference to SEAS 0** |
| SEAS €0/t$CO_2$eq | 255.6 | 106.4 | 209.1 | 38.0 | 609.0 | |
| **2050/2020, share** | **0.89** | **0.59** | **0.81** | **0.57** | **0.77** | |
| SEAS €10/t$CO_2$eq | 267.4 | 106.3 | 232.1 | 41.8 | 647.6 | 38.6 |
| **2050/2020, share** | **0.93** | **0.59** | **0.89** | **0.63** | **0.82** | |
| SEAS €20/t$CO_2$eq | 278.6 | 114.0 | 244.9 | 48.4 | 686.0 | 76.9 |
| **2050/2020, share** | **0.97** | **0.63** | **0.94** | **0.73** | **0.87** | |
| **LARGE DIET CHANGE SCENARIO (LDC) in 2050** | | | | | | **Difference to SEAS 0** |
| SEAS €0/t$CO_2$eq | 229.4 | 73.6 | 162.2 | 21.6 | 486.9 | |
| **2050/2020, share** | **0.80** | **0.41** | **0.62** | **0.32** | **0.61** | |
| SEAS €10/t$CO_2$eq | 255.7 | 72.1 | 176.3 | 24.7 | 528.8 | 41.9 |
| **2050/2020, share** | **0.89** | **0.40** | **0.68** | **0.37** | **0.67** | |
| SEAS €20/t$CO_2$eq | 268.2 | 77.7 | 191.6 | 31.1 | 568.6 | 81.7 |
| **2050/2020, share** | **0.94** | **0.43** | **0.74** | **0.47** | **0.72** | |

implemented in the model as an exogenous shift of demand functions. The effectiveness of specific policy measures of the public sector, such as providing information on sustainable diets or changes in food taxes affecting the prices of different food products (and thereby diets) are not considered. Based on the literature (Powell and Chaloupka, 2009; Allais et al., 2010; Tiffin and Arnoult, 2011; Smed et al., 2016), moderate taxes and subsidies (under 20%) would generate only limited behavioural responses and changes in food consumption. In Finland, food consumed at home comprises 12-13% of the total household expenditures, therefore attaining huge changes in food demand by imposing taxes would be difficult. It is unlikely that a significant decrease in livestock products or increase in plant-based foods consumption can be driven by changing food prices via consumption taxes.

Concerning land use measures or policies, rewetting peatlands is not considered as an option due to the lack of data on costs. Rewetting peatlands, e.g., increasing the water level to 5–10 cm below surface – where it is possible - would decrease GHG emissions to relatively low levels (e.g., 3 t$CO_2$eq/ha per year; Kekkonen et al. 2019). However, the costs and applicable area for different rewetting options should be investigated first before these options can be thoroughly analysed by using economic modelling tools.

Regarding the DREMFIA sector model, this model does not account for farm level frictions in land use change or land market deficiencies but assumes allocation of farmland (with mineral or organic soil type) to the relatively most profitable use at the regional level. Hence, the GHG mitigation due to the emission abatement subsidy is likely to be exaggerated in the short run, but more realistic in the long run.

### *5.2. Main modelling results*

The results demonstrate that it is difficult to achieve a large reduction in GHG emissions from agriculture by just changing diet alone. The diet change scenarios without specific land use measures would only contribute GHG reductions of 1.3 Mt $CO_2$eq for the SDC scenario and 1.5 Mt$CO_2$eq for the LDC scenario. Land use measures are vital in reducing GHG emissions from agriculture since even at the level of €10/t$CO_2$eq of soil emission abatement subsidy (SEAS), agricultural GHG emissions would decrease by over 5 Mt $CO_2$eq per year in 2050 without any changes in diet. However, the combination of changes in diet and land use would produce the largest abatement in GHG emissions, whereby agricultural GHG emissions would decrease by 7 Mt $CO_2$eq per year for the SDC scenario and 8.5 Mt $CO_2$eq per year for the LDC scenario, if €10/t$CO_2$eq is paid to farmers for better management of peatlands. Vermont and De Cara (2010) used similar value for abatement payments (€10, €20 & €50/t$CO_2$eq) to conduct a quantitative review of the GHG abatement costs in agriculture that have been reported in 21 studies. Eory et al. (2018) emphasised on the importance of generating concise information on the costs-effectiveness of policy instruments aimed at reducing GHG emissions. This study suggests that implementing SEAS at the level of €10/t$CO_2$eq would decrease peatland use in Finnish agriculture by almost 80% in the long run, which is cost effective in reducing GHG emissions.

This result, however, might overestimate the effect of SEAS on the use of peatlands in agriculture, at least in the short run. Difficulties at the farm level might prevent rapid changes in cultivating peatlands, nonetheless on farms which might not find mineral soils available for production of cereals or other annual crops; meanwhile the sector model assumes that production of annual crops can be shifted to mineral soils within each region and subregion. Hence, the sector model, not explicitly considering the farm level frictions in land use, may overestimate the effects on land use with the SEAS payments (land use policy). However, there are good reasons to conclude that farmers will make repeated efforts to re-organise production on different soil types, if the incentives such as SEAS payments are consistently applied over several years or decades. Structural development with farm size growth and exit of smaller farms would make it possible to realise changes in land allocation of different soil types over time. Thus, static farm level model suggesting significant frictions in peatland use is not valid in this kind of long-term analysis. Instead, the sector model logic based on rational use of regional land resources is needed and more appropriate, despite the likelihood of overestimating the effects of SEAS payments in the short run. However, it is necessary to highlight that low SEAS payments might not result in such rapid changes in peatland use as indicated in our results, but the direction of the changes is very likely to be correct. Furthermore, the scale of change in peatland use would increase over time when farmers have more flexibility to re-organise their production on peatlands.

The current CAP system is keeping agricultural peatlands cultivated, hence peatlands in agriculture will not be released easily. If there is a significant decrease in the volume of milk production due to a decline in the consumption of dairy and beef products, there is a risk that peatlands will be used for cereals production in areas where the share of peatlands is relatively high. The reason is the lack of economically viable crops suitable for peatlands if grassland is no longer an option. Besides, peatlands are suitable for low fertilisation and extensive agriculture in Finland, such as grassland for milk production. As the need for grass fodder production decreases, peatlands are increasingly used for growing cereals that is causing high GHG emissions from agriculture. Therefore, it is vital to implement land use policies to steer the direction of using peatlands in agriculture. The results suggest primarily that the combination of changing both diet and agricultural land use is the most effective in mitigating GHG emissions from agriculture; however, the relatively most disadvantaged regions in Finland with high shares of livestock production and peatlands may experience major restructuring in agriculture and land use.

### *5.3. Justice considerations*

Structural injustices are formed when the background conditions are unfairly constrained and limit some people's opportunities (Kortetmäki, 2019; McGregor, 2019). Low temperature, changing weathers, and relatively short summer restrict the function and production of crops for agriculture in Finland. Particularly, the topography, soil types, and effective temperature sum over the growing season for Northern and Middle Finland are not favourable for pulses and bread cereals that are replacing livestock products in diet, while the production conditions for these crops are more favourable in Southern Finland and Ostrobothnia. Therefore, farm income is most affected in Northern and Middle Finland where employment opportunities are weak and working outside the farm is difficult due to low population density. The limited opportunities for farmers in Northern and Middle Finland cannot be ignored due to the different environmental background conditions and diverse capacities. Hence, demanding the same actions for all regions would be unfair and likely inefficient for climate justice.

From the just transition point of view, distributive justice is concerned with the fair distribution of the benefits and burdens of social cooperation (Robaey and Timmermann, 2019); thus, the soil emission abatement subsidy can partly compensate for the drop in farm income due to a decline in Finnish livestock consumption. However, there is a big disparity in the distribution of farm income among the four main agricultural regions in Finland due to a radical decrease (e.g., 2/3 reduction) in the consumption of livestock products. Land use measures alone, for better management of peatlands, do not create the disparity in farm income among the different regions compared to the diet change scenarios. Radical change that at the same time makes food systems fairer might still be possible Timmermann (2021). The combination of a small change in diet (1/3 reduction in livestock consumption) and better management of peatlands via land use measures may produce a large GHG abatement from agriculture along with moderate changes in the distribution of farm income among the main agricultural regions in Finland, if €20/t$CO_2$eq is paid to encourage farmers to take climate actions and avoid cultivation on carbon-rich peatlands. However, this payment does not fully offset the farm income loss in Middle and Northern Finland, thus alternative income from outside the farm is also needed. Aubert et. al (2021) simulated a scenario that focuses exclusively on climate issues for the French food system, and the results also indicate significant socio-economic impacts: an increase in the rate of farm closures, a reduction in agricultural income, and associated job losses in the agri-food sector.

There is procedural justice if the transition process is made transparent and fair among the main regions in Finland with the future CAP and national agricultural as well as rural policy to sustain livelihoods for disadvantage regions such as Northern and Middle Finland due to a decline in livestock consumption. The soil emission abatement subsidy can compensate farmers for better management of peatlands in Finland without forcing farmers with strict regulations to transition from cultivating peatlands with organic soils to mineral soils. Opportunities should be given to the affected stakeholders to voice out their concerns in order to facilitate a just transition in the Finnish food system. Good decision-making requires a person to be informed and tackle the problem from all available angles. It is important to have in-depth knowledge and research to make an informed choice. An informed decision involves analysing the potential outcomes, benefits and risks associated with each option before deciding which is the best choice. Therefore, in-depth knowledge from research studies can help in the decision-making process in the transition towards low carbon pathways. Fully informed farmers may agree to assume disproportional burdens due to the additional opportunities they have in an emergency to combat climate change, despite the unfairness in distributing the burden of social cooperation. In the effort to reduce GHG emissions and promote long-term sustainability, the major ethical dilemma is that some distributional injustices need to be accepted to do justice for future generations who are inheriting the planet earth.

## 6. Conclusions

There is a need to investigate how agriculture could reach sizable reductions in GHG emissions, what might be the production implications and socioeconomic consequences, and how large might be the differences in the impacts between different regions with different conditions for agriculture. This study, based on agricultural sector modelling, shows how changes in diet and specific land use measures can reduce GHG emissions from Finnish agriculture, and what are the impacts on regional levels of agricultural production, land use, GHG emissions, and farm income.

The results demonstrate that it is difficult to achieve a large reduction in GHG emissions from agriculture by just changing diet alone. According to the diet change scenarios, there is a big disparity in the distribution of farm income among the four main agricultural regions in Finland due to a radical decrease in the consumption of livestock products. However, land use measures alone do not create the disparity in farm income among the different regions compared to the diet change scenarios as well as enable large reduction in GHG emissions. The combination of changing both diet and agricultural land use is the most effective in mitigating GHG emissions from agriculture; however, the relatively most disadvantaged regions in Finland (Middle and Northern) with high shares of livestock production and peatlands may experience major restructuring in agriculture and land use.

There is a problem in how to ensure a just transition for farmers in livestock dominated regions with poor production conditions for special crops (e.g., legumes) and weak employment opportunities. Soil emission abatement subsidy for peatlands may provide partial income compensation, but unable to offset the high loss of farm income to sustain their livelihoods. It is essential to find other sources of income and alternative uses for the abandoned agricultural land. The disadvantaged regions in Finland need public guidance and assistance for alternative livelihoods in the transition towards low carbon pathways. Developing new products and value chains for crops to be grown on re-wetted peatlands may provide alternative sources of income for farmers in the future. From the private sector, relevant actors in the food value chain such as the processing and retail sectors together with consumers are also important in facilitating a just transition in the Finnish food system.

## Declaration of Competing Interest

As authors of the paper "The transition of agriculture to low carbon pathways with regional distributive impacts" we declare no conflict of interest.

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