Policies to reduce GHG emissions from agriculture, their implications for agricultural activity levels and land use decisions in Ireland

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Abstract

To prevent the most damaging effects of climate change, the Intergovernmental Panel on Climate Change (IPCC) have identified the need to limit the rise in the global average temperature to 1.5°C above pre-industrial levels. In support of the goal of climate change mitigation, Ireland's Climate Action Plan has set a goal of reducing overall greenhouse gas emissions by 2030 and setting us on a path to reach net-zero emissions by 2050. As part of the plan the agriculture sector has been set of 25% reduction target relative to 2018. This paper utilises the CAPRI model to evaluate the effect of a hypothetical €100 carbon tax on non-CO2 emissions for agricultural. Results revealed that under a €100 carbon tax, overall GHG emissions would decrease in large part due to a decrease in beef meat activities, which is along with the dairy sector the dominant source of methane emissions in Irish agriculture. Average agricultural income would be projected to increase due to less profitable production exiting under carbon tax and price. A significant increase in the area of set aside and fallow land is also observed, which leads to a reduction in agricultural land and can be used for an increase in afforestation.

Keywords: Carbon Tax, Land Use, GHG emissions, CAPRI model, Ireland

1. Introduction

The Intergovernmental Panel on Climate Change have identified the need to limit the growth in average temperatures to 1.5°C above preindustrial levels in order to avoid the most serious negative effects of climate change (IPCC, 2018). Limiting the growth in temperatures to 1.5°C (net-zero emission) will not avoid climate change and the associated economic costs, however the overall costs would be lower than the costs incurred if those targets are not met. By acting early it does allow economies to be gradually adjusted to the negative impacts of climate change and can help to lower the overall costs of meeting these targets (WB, 2021). Therefore, to support a long-term climate plan, the EU countries committed to reaching carbon neutrality by 2050 and reducing their Greenhouse Gas (GHG) emissions by 55% by 2030 compared to the 1990 levels (European Commission 2021). Recognizing the urgency for climate action, Ireland is stepping up its nationally determined contributions (NDCs) to align with this target (EPA, 2021).

The agriculture sector is the single largest source of GHG emissions in Ireland accounting for 37.5% of national GHG emissions in 2021 (EPA, 2022). Despite the growing awareness of the need to reduce GHG emissions, emissions from agriculture in Ireland have been increasing largely due to expansion in the national dairy herd as part of a national strategy to capitalise on the opportunities presented by the abolition of the EU milk quota regime. Recognising the need to address GHG emissions, government legislation in Ireland targets a reduction in GHG emissions of 51% by 2030 (relative to 2018), with a 25% (5.75 Mt) reduction in emissions from agriculture (Climate Action Plan, 2023).

In Ireland, agriculture accounts for about 60% of the total land area, which is considerably higher than the EU average of 40% (CSO, 2016). Of this agricultural land 80% is allocated to grassland e.g. silage, hay grass and pasture, with the Irish agricultural sector being predominantly dominated by grass-fed livestock farms and rough grazing accounting for a further 10% of the land area. Given the predominance of grass based livestock production systems in Ireland, it has become a significant net exporter of meat and dairy products. As a result, unlike many other developed countries, the agriculture sector in Ireland also makes a significant contribution to the Irish economy, accounting for 14% of Gross Value Added (CSO, 2016). Therefore, reducing emissions from agriculture while minimising the impact on the returns to the agri-food sector as well as the wider economy presents a significant challenge for policymakers in Ireland.

Policies that place a price on carbon are considered to be an effective tool for mitigating carbon emissions, in that by pricing carbon it sends a signal to farmers to adopt mitigation practices. Responding to a range of factors, circumstances, and policy objectives, carbon pricing can be explicitly implemented. Therefore, carbon pricing can apply through a carbon tax, an Emissions Trading System (ETS), or a crediting mechanism, in which one of them will apply depending on each instrument's advantages, and social circumstances. Furthermore, in addition to reducing GHG emissions such a system of emissions tax can help to redistribute income and reduce inequality (Pryor et al., 2021). However, while such a policy creates a strong incentive to reduce carbon emissions, it may be detrimental to economic growth (Liu & Lu, 2015; Caillavet et al., 2017; Liu et al., 2018).

A carbon tax is typically suggested when revenue certainty is a priority and/or where there are institutional or technical capacity constraints. When there is a recognised barrier to public acceptance of a carbon tax, an ETS is routinely applied, as well as when achieving an emissions target is a priority. Also, where the implication of a carbon tax or an ETS faces barriers such as legal hurdles or political resistance, carbon crediting may be applied (WB, 2021). As the carbon tax policy sets the marginal cost of emission equal for every source across the economy, it is one of the most effective, and cheapest ways of meeting the national emission target (Liu et al., 2018). Besides this, a carbon tax is introduced as the best tool to incentivize reductions across the economy (WB, 2021).

Under the carbon tax a price for GHG emissions on the basis of a tonne of CO_2 equivalents will be determined to establish a direct link between the GHG emissions of a product or process and the tax that must be paid on it (WB, 2021). However, reviewing the literature suggest that a carbon tax might simultaneously stimulate economic activity whilst reducing emissions and thus secure an increase in revenue (Allan et al., 2014; Caillavet et al., 2017). Consequently, it is necessary to scientifically study the multiple effects of a carbon tax on the economic system so that an effective economic strategy for GHG emission reduction can be determined.

1.2. Study area

Before, presenting the methodology a brief overview of farming in Ireland has been provided to conceptualise the implication of carbon tax in Ireland. For EU unity Policy purposes, Ireland is designated into two NUTS[1] 2 regions due to the regionalisation arrangements negotiated by the Irish authorities in the context of the Agenda 2000 Agreement. These two regions, which were established in 1992, are Border, Midlands, and Western (BMW), and Southern and Eastern (SE) regions. The BMW region (containing 53% of total farms) is characterised by its higher prevalence of beef and sheep farms as well as smaller farm sizes on average while the SE region (56% of the agricultural area) is characterised by larger farms and a higher proportion of dairy and tillage farms. Besides, the economic size of the SE region is considerably higher than BMW, where the average standard output in SE is about 65000 Euro and the average standard output in BMW accounts for 29000 Euro (CSO, 2016). Therefore, the carbon tax policy would differently influence these regions as the farm structure is different in these regions.

In the agricultural context, in particular, in Ireland, the farm returns to enterprises substantially vary. For instance, the average Family Farm Income (FFI) for dairy (€98700) is considerably more profitable on average than beef (€10900) or sheep (€20800) farms (NFS, 2021). Accordingly, a beef or sheep farmer would be more likely to reduce activity levels given the low returns to these enterprises, while a dairy farmer may be able to absorb a tax and keep on farming at the same level of intensity. Thus, the response that both sets of farmers are likely to make to such a carbon tax is likely to be different. Subsequently, examining the potential impact of a carbon tax in Ireland with a regional demotion is necessary for this paper, the effect of the carbon tax as the policy scenario has been evaluated considering a regional dimension within Irish agriculture.

2. Methodology

The Common Agricultural Policy Regional Impacts (CAPRI) model is used to evaluate the potential effect of a hypothetical carbon tax on non-CO_2 emissions. CAPRI is a large-scale, comparative-static, agricultural sector model, which consists of two interacting modules. The two modules are linked through an iterative procedure (Van Doorslaer et al., 2015; Fellmann et al., 2018).

The supply module, a highly detailed, disaggregated, and non-linear programming model, optimizes policies and technologies based on farm models. In this module, farming decisions are depicted in detail at the NUTS 2 and farm type levels for approximately 280 European regions. As such, with the supply module, the potential effects of a future policy/intervention at a regional level can be compared against a reference scenario that assumes a continuation of the current policy. The impact

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[1] NUTS „Nomenclature des Unites Territoriales pour Statistiques" is the term given to the EU regional classification system.

of alternative policy scenarios on regional agricultural income, input and output price, subsidy level, etc. can be examined, while technologies comprise ‘high yield, high input’ and ‘low yield, low input’ systems. The supply model covers approximately 55 farm inputs and 60 activities, which comprise inputs to crop and livestock production. Within the supply module, the land is the primary constraint on agriculture production levels (Adenaeuer et al., 2021) along with rent (rent is different among different land use), policy, the supply of inputs such as young animals, manure, and fodder as well as feed and plant nutrient requirements for each region which also constrain agricultural supply (Gocht et al., 2017; Himics et al., 2018). Therefore, each supply model in the CAPRI model maximises the regional agricultural income subject to land constraints, nutrient balances, and policy requirements.

The market module is a comparative static, deterministic, spatial, global partial equilibrium model which explain 60 primary and secondary agricultural products. The CAPRI model also considers international trade, simulating supply, demand, and price changes in global markets within the market module (for 80 world regions, which are aggregated into 44 trade regions). The CAPRI model will find the market equilibrium point by iterations between the supply module and the market module using a comparative-static analysis based on changed policies or technologies (Cortignani et al., 2017; Gocht et al., 2017). In this module, the international trade will be constructed based on an armington assumption meaning all goods are modified by place of origin following the consumer preferences derived from the historical trade patterns. Thus using the armington approach allows countries to have various bilateral and multilateral trade instruments (Britz & Witzke, 2014).

One of the most important advantages of CAPRI compared to other agri-economic modelling approaches is the ability to cover the heterogeneity in farm production systems and to model environmental effects and market (price) feedback of the simulated policy scenarios at the regional, national, and EU-wide levels (Gocht et al., 2017; Himics et al., 2020).

Both CO_2 and non-CO_2 GHG emissions are subject to climate change policies in many countries around the world (Nong et al., 2021). Despite this there are still many impact assessment studies in different regions that consider only CO_2 emissions, in this paper the impact of non-CO_2 greenhouse gas emissions on agricultural activities is hypothesised. Therefore, a carbon tax scenario is implemented where a tax of 100 €/t of CO_2eq is levied on additional GHG emissions in excess of historical levels from the agricultural sector for all EU countries under the market module. The GHG emissions dataset within the CAPRI supply model follows the IPCC guidelines (IPCC, 2006) in quantifying emissions with a Tier 2 and Tier 1 approach used for the calculation of activity-based emission factors. Thus, the CAPRI model endogenously calculates EU agricultural GHG emissions for nitrous oxide (N_2O) and methane (CH_4) based on the inputs and outputs of the production activities modelled.

2.2. Reference scenario assumptions

The reference scenario is calibrated based on information available mid-2016 (e.g., abolishing the EU milk and sugar quotas) and only considers agricultural, environmental and trade policies that are already ratified (Britz & Witzke, 2014). The reference scenario is calibrated to the European commission’s outlook for agriculture markets and income (Britz & Witzke, 2014). According to the OECD-FAO (2015) agricultural market, the reference scenario gives a mid-term projection by 2025 based also on macroeconomic assumptions (e.g. GDP growth, population growth, exchange rates, and world oil prices) from external sources in a consistent framework. Thus, the European Commission’s projections with other information are completed to project the reference scenario by 2030.

A scenario of 100€/tCO_2eq is selected as a policy scenario due to two reasons. Firstly, the carbon tax is considerably increasing over time on the amount of 33.5 to 41 per ton of carbon dioxide (CO_2)

emitted in Ireland (NGCT, 2022). Secondly, that the carbon tax rate in some EU countries like Germany is fluctuating between 50 t0 100 €/tCO_2eq, or it is increasing annually by 10% to reach 100% in 2028 in Argentina (WB, 2022).

2.3. Carbon tax scenario assumptions

Under the carbon tax (policy) scenario, the impact of the carbon tax in 2030 will exogenously be quantified relative to the reference scenario (2012), which is calibrated to the European commission's outlook for agriculture markets and income (Britz & Witzke, 2014). In the CAPRI model, the policy scenario, is used to investigate the potential impacts of a tax of €100 per ton of CO_2 equivalents on methane and nitrous oxide emissions from agricultural activities. According to the carbon tax scenario, the non-CO_2 emissions simulate in 2030, and will compare to the level of farm activities/emissions in the reference scenario. The carbon tax scenario provides an economic signal to farmers and allows them to decide to either transform their activities and lower their emissions or continue emitting while paying for their emissions. In the other words, farmers can continue to produce their historic level of emissions but where emissions surpass that level they are subject to a tax at quite a high rate. Additionally, if farmers reduce their emissions below the historical level of emissions (relative to the emissions level in 2012) they will receive a subsidy payment, in which they can increase their average income, consequently. Therefore, the carbon tax is rather a subsidy and applied only to additional emissions, where the baseline emissions are granted free.

3. Results

The following section details the projected impacts of the carbon tax on agricultural production activities in Ireland and the related GHG emissions compared to the reference scenario in 2030. Results show that the introduction of a carbon tax would significantly alter agricultural production in Ireland.

Table 1- animal activity Herd size (heads) changed under carbon tax

Region	BMW	SE	Ireland	EU
Cattle activities	-12.14%	-10.69%	-11.29%	-7.42%
Beef meat activities	-15.69%	-16.39%	-16.05%	-13.41%
Dairy	-6.34%	-5.84%	-6.01%	-4.55%
Sheep and Goat fattening	-9.32%	-9.69%	-9.46%	-7.23%

As can be seen in Table 1, the carbon tax has a significant impact on the livestock sector in Ireland, with beef meat activities projected to undergo a substantial decrease in herd size (16%), which is higher than the projected reduction across the EU (13.4%). However, the projected reduction in dairy cow numbers is not as larfe (6%), but this still reflects a larger decrease than for the EU (4.5%). Farm activities are reduced, as farmers aim to limit their production costs related to emissions under the carbon tax scenario.

Comparing the two economic regions in Ireland shows that the herd size in both BMW and SE would decrease under the carbon tax scenario, however the percentage change would be slightly higher in the BMW region. Although a slightly larger percentage change in dairy herd size is reported for the BMW region (6.34% in the BMW compared with 5.84% in the SE), the actual reduction in dairy cow numbers would be greater in the SE region, with dairy cow numbers in the SE projected to decrease by 92,390 cows compared with 49,540 cows in the BMW region, due in large part to the higher concentration of dairy farms in the SE region. Despite, a similar percentage change in sheep and goat herd size in both BMW and SE regions, a greater reduction in the number of sheep and goats is anticipated in the BMW (BMW=119500 and SE=75330 heads), again this is in large part due to a higher concentration of sheep and goat farms in the BMW region especially in the marginal upland areas along the western coastline.

Table 2- land use activity (hectares) changed under carbon tax

Region	BMW	SE	Ireland	EU
UAA[1]	-0.73%	-0.69%	-0.72%	-1.25%
Cereals	0.39%	-1.64%	-1.12%	-3.38%
Grass and grazing intensive[2]	-31.07%	-30.63%	-30.82%	-16.17%
Set aside[3] and fallow land	4.22%	22.69%	17.57%	12.32%
Fallow land[4]	11.19%	42.78%	38.82%	13.66%

1. "*The Agricultural Area Utilised (UAA) is the combined area under crops, silage, hay, pasture and rough grazing land in use (including fallow land). Areas under roads, tracks, water, bog, marsh, rocks, unused rough grazingland, buildings etc. are excluded*" (CSO, 2016).
2. "*For the grassland, the model distinguishes two types with different yields (GRAE: grassland extensive, GRAI: grassland intensive) so that idling grassland can be expressed of an average lower production intensity of grassland by changing the mix between the two intensities*"(Britz, 2005).
3. "*Obligatory set-aside areas must be equal to the set-aside obligations derived from areas and set-aside rates for Grandes Cultures (which may differ at regional level according to the share of small producers)*" (Britz, 2005).
4. "*The necessary additional information on non-food production on set-aside, obligatory and voluntary set-aside areas can be found on the DG-AGRI web server* " (Britz, 2005).

The reduction in the total Utilized Agricultural Area (UAA) in Ireland is small at 0.72% (UAA in the EU decreased by 1.25%) and is mostly due to a 1.12% decrease in the area under cereals. On the other hand, the area under set aside and fallow land increased by 17.6% (4570 ha), which depicts a further reduction of arable land. The percentage increase in set aside area and fallow land in Ireland is significantly higher than in the EU (12.3%, 1055880 ha), however, this reflects the low base area for set aside and fallow land and the relative small share of the total area in setaside in Ireland under the reference scenario when compared with the area of land in setaside in other EU countries.

The area of intensively farmed grasslands in both the BMW and SE regions decreases significantly as a result of the carbon tax scenario, with a decrease of almost 30% in the area of intensively farmed grasslands in Ireland, which is doublethe projected percentage decrease in the intensive grassland area across the EU (16%) (Table 2). As most cereals have been planted in the SE and specialist tillage farmers are predominantly located in this region, the percentage change in the area of cereals as a result of the carbon tax scenario is greater in this region. The cereals in the SE have decreased while cereals plantation have been increased in BMW. These results are likely due to farmers switching some land from beef and sheep production to cereals. Although the change in UAA (both cereal and others) is reported almost at an equivalent percentage in both regions, the absolute change in SE (18100 ha) region is greater than BMW (12220 ha), reflecting the concentration of UAA in the SE. Finally, the 'Set aside and fallow lands' and ,'Fallow lands' in SE rise to a bigger extent compared to BMW under the carbon tax scenario (Table 2).

Table 3- Price (Euro/t) Change under carbon tax

Region	BMW	SE	Ireland		EU	
	Producer Price	Producer Price	Consumer Price	Producer Price	Consumer Price	Producer Price

Cereals	3.20%	3.32%	0.15%	3.29%		3.80%
Meat (products)	8.07%	9.04%	2.40%	8.57%		5.66%
Beef	12.29%	12.29%	5.53%	12.29%	6.41%	12.30%
Pork meat	5.64%	5.64%	1.23%	5.64%	1.65%	5.59%
Sheep and goat meat	5.39%	5.39%	2.67%	5.39%	3.26%	6.11%
Poultry meat	1.79%	1.79%	0.71%	1.79%	0.81%	1.89%
Cow milk	6.56%	6.56%		6.56%		8.47%
Fresh milk products			1.79%	3.00%	2.12%	3.45%
Skimmed milk powder			0.90%	1.34%	0.87%	1.38%
Whole milk powder			0.63%	1.57%	0.78%	1.63%
Cheese			2.02%	3.45%	2.29%	3.66%
Butter			2.90%	5.45%	3.27%	5.48%

Because of higher costs and reduced production activities for the producers under the carbon tax scenario, consumer and producer prices are projected to increase for all farm activities. According to Table 3, under the carbon tax scenario, both consumer and producer prices have increased in Ireland and the EU, reflecting a decrease in both livestock numbers and cereals production as a result of the carbon tax. The largest increase in producer price has been observed by the livestock sector (meat products namely beef, and milk), followed by cereals as a non-animal related sector. Compared to producer prices, consumer prices rise to a lesser extent. Consumer price for beef increases by 6.4% and butter by 3.3% in Ireland, which will be reflected by a lowered human consumption of these products. Consumer prices of fresh, skimmed, and whole milk powder are barely affected by the carbon tax scenario, nationally and EU-wide (Table 3).

The projected increase in producer prices for meat products is slightly higher in the SE region, which is projected to experience a bigger reduction in the beef herd when compared with the BMW region (Table 1). The biggest projected change in producer prices is in the price for beef (12.29%), which is a result of the projected reduction in beef cattle numbers as well as increasing prices across the EU for the other substitute meat products including pork, sheep, and poultry meat products' prices which are all expected to increase also as a consequence of the carbon tax (Table 3).

Table 4- Animal activities and land use income (Euro/ha or head) changed under the carbon tax

Region	BMW	SE	Ireland	EU
All cattle activities	52.39%	30.40%	37.20%	37.39%
Beef meat activities	91.75%	55.94%	71.13%	146.09%
All dairy	29.24%	20.88%	23.40%	25.28%
Sheep and Goat fattening	8.32%	6.56%	7.42%	0.57%
Cereals	11.45%	13.52%	12.99%	23.24%
Grass and grazing intensive	-84.85%	-43.07%	-57.27%	-230.82%

Under the carbon tax scenario, the average income is projected to increase with the exception of grass and grazing activities, the increase in average incomes is a result of higher producer prices and also due to farms deriving revenues from subsidies for reducing farm emissions (Table 4).

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The beef sector is projected to show the highest increase in average incomes relative to the reference scenario and this is in part due to the large increase in beef prices projected under the scenario as well as the fact that the returns to beef production in Ireland are typically lower than other enterprises with many beef farms heavily reliant on direct payments Thus, the increase in income in the livestock sector in the BMW region is significantly higher than in SE, and is likely to be in part due to the exiting of less profitable beef production. Moreover, non-animal related activities contribute to the increasing agricultural income as income for cereals increases by around 11.5% (in BMW) and 13.5% (in SE), reflecting more cereal fields in SE. Regarding the grass and grazing activities, income has decreased, in which the income in BMW decreased to a greater extent (doubled). Therefore, the income-related land use activity has decreased, and significantly a bigger change has been observed in SE, where farms are reported for a bigger economic size. This result could be influenced by the difference in farm structures between the two regions with the BMW region containing a higher proportion of small-scale low profitability dry stock farms than in the SE of the country (Table 4).

The change in global warming potential from agriculture and fertiliser use under the implementation of the carbon tax scenario is reported in Table 5.

Table 5- GHG emissions and fertiliser changed under carbon tax

Region	BMW	SE	Ireland	EU
Global warming potential from agriculture	-12.39%	-10.63%	-11.33%	-6.28%
Mineral (synthetic) nitrogen - [N kg/ha]				
Cereals	-5.14%	-5.35%	-5.37%	-2.45%
Grass and grazing intensive	-7.90%	-6.88%	-7.22%	-8.80%
Manure nitrogen - [N kg/ha]				
Cereals	-2.11%	-0.67%	-1.03%	-0.31%
Grass and grazing intensive	-1.71%	-0.35%	-0.93%	-3.70%

As can be seen in Table 5, imposing the carbon tax on non-CO_2 agricultural emissions achieves a reduction of 6.3% in GHG emissions from agriculture within the EU, and a reduction of 11.3% in Ireland, as a result of reduced agricultural activity. As a result of the reduction in agricultural activity levels a reduction in the application of chemical Nitrogen fertiliser would also be anticipated, with the projected reduction in Ireland being significantly higher in Ireland than in the EU.

GHG emissions from agriculture are projected to decline in both regions of Ireland, although the reduction was slightly greater in the BMW region in percentage terms. Generally, the reduction in emissions is largely due to a decrease in the emissions from livestock production, particularly reduced numbers of dairy and beef cattle both of which are associated with high levels of methane output (Table 5).

The reduction in the use of synthetic fertiliser to produce cereals will be slightly higher in the SE region than in the BMW, which is a result of a decrease in hectares of cereals. According to Table 5, the synthetic fertilisers are reduced to a larger extent in the SE, while the manure fertilisers declined more in BMW, reflecting a decrease in livestock numbers in the region. This result could be influenced by the difference in farm structures between the two regions with a higher concentration of beef and sheep production in the BMW region and cereal production being more prevalent in the SE region (Table 5).

While the primary goal of the carbon tax is to reduce GHG emissions, the reduction in production activities will deliver other environmental benefits in addition to reduced GHG emissions.

Table 6- Other environmental indicators (1000t or kg per ha N) change under the carbon tax

Region	BMW	SE	Ireland	EU
Total surplus N	-28.68 (-15.74%)	-39.67 (-13.89%)	-14.61%	-6.64%
Total surplus P2O5	-10.86 (-15.44%)	-16.21 (-13.88%)	-14.47%	-8.56%
Total surplus K2O	-27.4 (-16.13%)	-38.28 (-14.72%)	-15.28%	-8.67%
Ammonium output	-3.64 (12.19%)	-4.95 (-10.04%)	-10.85%	-5.05%

Table 6 shows the most important environmental indicators such as Nitrate (N), Phosphate (P_2O_5), and Potassium (K_2O) have decreased in both Ireland and the EU, the extent of the reduction in the surplus of NPK is substantially higher in Ireland than for the EU as a whole. Although ammonia is not a GHG, like GHG emissions ammonia emissions are largely a function of agricultural activity levels. Furthermore, ammonia can indirectly contribute to GHG emissions by the management of animal manure, animal grazing, and synthetic fertilisers (Climate Action Plan, 2023). Ammonia emissions in Ireland significantly decrease as a result of the introduction of the carbon tax and the reduction in herd size and area farmed that this brings about in Ireland. Under the effect of the carbon tax on ammonia emissions, the emissions decrease per hectare can reach 12.19% in the BMW region with a higher level of cattle activity. The decrease in emissions measured in the SE may be a result of the increase in fallow land resulting in a decrease in cereals, with the subsequent decrease in ammonia from synthetic fertiliser. A lower decrease in the environmental indicators in the SE, with a higher dairy and cereal density, could be influenced by higher consumption of fertiliser on the dairy and cereal farms (Table 6).

Despite a greater decrease in the total surplus of NPK in BMW compared with SE as a result of the carbon tax, when it comes to its impact on GHG emissions, the carbon tax will be more effective in reducing GHG emissions through reducing herd size in both regions. A decrease in herd size will remarkably reduce GHG emissions, in particular in BMW. Considering the fact that cattle are the main source of GHG emissions in BMW, the carbon tax implication can remarkably decrease the herd size which means a considerable decrease in GHG emissions in this region. Besides, along with decreasing the herd size in SE, this policy will also decrease the use of synthetic fertilisers (e.g. NPK, ammonia). Therefore, two major sources of GHG emissions in SE will be effectively reduced as a result of the carbon tax scenario. Accordingly, this policy is potentially deemed an effective tool for decreasing GHG emissions in Ireland.

Table 7- Import (1000 t) and human consumption (kg/capita and year) change under the carbon tax

	Import		Human consumption	
Region	EU-East	EU-West	EU-East	EU-West
Cereals	-7.75%	8.82%	-0.15 (-0.12%)	-0.15 (-0.15%)
Dairy products	-5.89%	-0.02%	-0.77 (-0.92%)	-0.50 (-0.44%)
Meat	4.85%	-0.86%	-0.99 (-1.52%)	-0.24 (-0.34%)

As can be seen in Table 7, the import quantity and human consumption in the EU are also influenced by the introduction of the carbon tax scenario. Related to the increasing consumer price for the reported agriculture activities in the EU countries, the demand for feed is shrinking, reflecting a decrease in the import quantity of feed-related agricultural products. Considering a drop in the import of cereals in hectares and animal herd size (dairy and beef), these products are increasingly imported in eastern and western EU countries, respectively. However, the trade quantity in eastern EU countries, the cereals and dairy products significantly decreased compared with western EU countries. These results could be influenced by the decrease in human consumption in the eastern EU countries (Table 7). Human consumption of animal products (dairy and meat) has also decreased as the consumer price for these products has increased (Table 3). Consequently, under the introduction of the carbon tax the import has decreased however, its effect is modified under the impact of the decrease in human consumption (Table 7).

4. Discussion and conclusion

Despite the broad application of carbon tax mostly at an international level, to the best of our knowledge, the regional impact of this policy has been neglected. This is important for countries such as Ireland whereby farming systems are diversified regionally and the source of GHG emissions vary in different regions, where there is a need for flexible policies to target the different sources of GHG emissions. This paper attempted to depict a clear picture of whether or not the carbon tax can reduce GHG emissions in different regions as an effective tool to be applied by policymakers and regulatory systems in Ireland. To a better understanding of the future potential of the carbon tax in reducing GHG emissions in both regions, this paper seeks to analyse the regional impact of the carbon tax by evaluating the effect of the carbon tax on the different regions/enterprises in Ireland, namely BMW and SE.

Interestingly this study shows that the introduction of a €100 carbon tax reduces agricultural emissions in Ireland by 11% which is considerably greater than in the EU as a whole (reduction of 6%). This result implies that the livestock sector, which is a major source of emissions in Ireland, responds through a reduction in production as evidenced by a reduction in the herd size. Despite this, the farm income will increase as less profitable farms can substantially reduce herd sizes and receive a subsidy of €100 per tonne of CO_2eq abated. Besides, under the influence of the carbon tax scenario, the producer price for farm activities (cereals land use and animal activities) has increased, which increases the farm income, as well. Therefore, farmers in the BMW region are projected to reduce their emissions to a greater extent compared with SE under the carbon tax scenario. As a result, the farm income is projected to increasel significantly, in particular, for beef meat activities in the BMW region. Emissions reduction is increasingly achieved through a reduction in production levels under the €100-carbon tax scenario, which affects regional food consumption levels, in particular, animal-based consumption. Generally, ruminants are identified as a key sector for climate change mitigation, contributing across models and carbon tax scenarios, which mostly can be found in BMW. This finding is important as farmers in BMW are less profitable and need such policies, which can enhance their profitability while reducing GHG emissions. On the other hand, under the influences of the carbon tax, the import would increase, in particular in, meet activities, however, the increase in import has been modified by a decrease in animal product consumption. Finally, a higher reduction of the cattle activity in herd size in BMW followed by a greater increase in fallow lands in the SE region potentially reduces agricultural GHG emissions in Ireland. It offers policymakers to make a plan for new emissions reduction and land use-related policies, such as afforestation. Additionally, it leads farmers to a higher level of income through the financial support provided by grants and premium payments currently in place under the national afforestation scheme.

Noteworthy, the carbon tax will be effective from a policy point of view, however, there is still a need for better communication and knowledge-transferring programs to assist farmers in perceiving the long-term benefit of the policy. It highlights the fact that farmers should be well aware of and engaged in such policies, however, the CAPRI model does not cover individual social decision behaviour (Hayden, et al., 2019). Accordingly, further research should focus on understanding farmers' perceptions, attitudes and educational needs toward the carbon tax. Furthermore, since this study aims to introduce and examine the potential effect of the carbon tax in general, further research is warranted on understanding different tax strategies, such as ETS and crediting mechanisms on GHG emissions in Ireland.

5. Critical Assessment of the Results

Despite the application of the most proper model namely CAPRI, there are still a number of limitations associated with the model assumptions to be considered for the findings interpretation. Like almost all global agro-economic models, farm characteristics (e.g. farm size) is not fully considered under the simulated policy/climate impact by CAPRI. Although the CAPRI model includes the global market model for the agricultural sector, the potential interaction of the non-agricultural sector are neglected in this model. Despite the confirmation of regional analysis as an appropriate and precise model, there is a limitation of a little bit of overestimation in findings using such analysis. As non-EU emission intensities calculation is based on historic emissions and production data from FAOSTAT, improved emissions efficiency (e.g. allocating climate funding, and fertiliser efficiency) over time has been neglected. Therefore, the projection analysis of emissions by 2030 will lead non-EU countries' emission intensities might be inevitably overestimated regarding the results (Himics et al., 2018). Additionally, in this paper the proposed results do not consider the mitigation options which would if included likely allow for smaller reductions in activity levels in response to the introduction of the carbon tax. Despite these limitations, the paper shows the potential effect of the carbon tax introduction, and depicts the economic and environmental effects covering the regional, national, and EU wide level.

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