Impacts of aligning greenhouse gas efficiency and international trade in agricultural commodities

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Abstract

Improving access to sufficient, nutritious, and affordable food for a growing global population, combined with institutional and technological constraints, have complicated efforts to reduce greenhouse gas (GHG) emissions from agriculture. As a significant contributor to GHG emissions world-wide, this is frustrating overall ambitions to mitigate the impact of human activities on the climate system. This paper investigates the role that trade policy could play, independent of national action plans, to improve the overall GHG emission-efficiency of agricultural production globally. A mechanism to internalise *relative* emission-efficiency between trading partners as a component of competitiveness is considered. Utilising a partial equilibrium model of crop and livestock agriculture in England, Wales, Scotland and Northern Ireland (FAPRI-UK) a hypothetical Relative Emission Border Adjustment (REBA) is applied to grain, meat and dairy commodities crossing the United Kingdom (UK) border. At the global-scale, such a tariff mechanism reduces agricultural emissions by shifting production to countries that are relatively *more* emission-efficient (holding consumption constant). The impact on national-scale GHG emissions is found to be context dependent. Potential mismatches between the UK's comparative advantage in emissions for a commodity at global, versus national-level, and, dynamics of the UK's production response with a REBA in place, particularly in the cattle-based sector, shape the impact. The analysis shows that while progress towards global emission-reduction- targets improves under the mechanism, this is not always compatible with achieving national targets. This raises issues about the potential of a trade-based mechanism to complement, rather than replace, national priorities and policies. At a more fundamental level, the analysis raises questions about the wisdom of setting binding national targets that ignore international comparative advantage in low emission production.

Keywords

Greenhouse gas policy; Carbon-leakage; Carbon Border Adjustment; Food system decarbonisation

1 Introduction

Food is a form of chemical energy made available to humans in the form of proteins, carbohydrates and fats that are contained in plant and livestock products. Food production depends on natural and synthetic inputs and is a component of the overall global energy system which is subject to internal variability, but from a global perspective, remains relatively stable until a structural shift disturbs the long-term equilibrium such as the Earth absorbing more energy from the sun than it has been radiating back into space leading to 'energy imbalance' and anthropomorphic induced global warming (Hansen, Sato et al. 2011). More recently von Schuckmann, Cheng et al. (2020) argue that the Earth Energy Imbalance (EEI) is the best single metric to measure climate forcing and by the same token efforts to bring climate change under control. Under this approach, the EEI needs to be reduced to approximately zero to regain a quasi-equilibrium state in the Earth systems. Food production[1] must play its part in restoring the energy system to equilibrium, by addressing the issue of greenhouse gas (GHG) emissions, primarily emissions of methane (CH_4) and nitrous oxide (N_2O) associated with livestock and crop farming.

There is variation in emission-efficiency (the average GHG emissions associated with generating one unit of output) across countries. For example, cow's milk produced in Pakistan generated an estimated 30 percent additional GHG emissions per unit of output than the global average, compared to that produced in the United States, estimated to generated 50 percent fewer emissions per unit (FAOSTAT Analytical Brief 50. 2022). These differences contribute to concerns related to perverse outcomes such as 'carbon leakage', when national GHG reduction policies result in the displacement of domestic production by imports with higher GHG footprints and a net increase in global GHG emissions. (Blandford, Gaasland et al. 2015, Dalin and Rodriguez-Iturbe 2016, Himics, Fellmann et al. 2018, Niu, Peng et al. 2020, Hu, Wang et al. 2021).

This paper proposes a mechanism to reduce emission leakage *via* international trade in agricultural commodities, to support reducing global agricultural emissions. A price adjustment (tariff) based on the *relative* emission-intensity of a specific agricultural commodity produced domestically, or by a trade partner, is implemented at the national border. This mechanism directly disincentivises trade of individual commodities by countries with relatively more GHG emitting production systems (discouraging carbon-leakage), and indirectly encourages production of that commodity to shift towards countries with relatively less polluting production systems (improving global agricultural emission-efficiency). The comparison of like-with-like (*e.g.* domestic beef *vs* imported beef; domestic butter *vs* imported butter; etc.) results in a range of differentiated tariffs across commodities that incorporates additional social cost into trade costs for more GHG-intensive commodities.

The objective of this paper is to simulate the adoption of such a mechanism at the border by the United Kingdom (UK) and to analyse the national (UK-level) impacts. Specifically, the expected impact on prices, production, trade, domestic use, GHG emissions, and soil nutrient balances under alternative assumptions depending on whether the UK, or the trade partner, holds the international emission-efficiency advantage. The next section describes the mechanism design and how relative, as opposed to absolute, emission-intensity is used to establish a commodity-specific tariff. The expected impact on global and national emissions is also provided to help explain why a simulation approach is required to anticipate the UK-level impacts. Section 3 provides information on the

[1] Globally in 2020, agrifood systems were responsible for 31 percent of all GHG emissions, of which 46 percent were generated on farms, 35 percent by pre- and post-production activities, and 19 percent from land-use change, with emissions from farming trending upwards on average FAOSTAT Analytical Brief 50. (2022). Greenhouse gas emissions from agrifood systems, Global, regional and country trends, 2000–2020.

model's methodology, structure, and key assumptions including how emissions are projected and the emission-intensity per unit of commodity output. The application of counter-factual scenarios to compare the UK holding an international emission-efficiency advantage (disadvantage) with a business-as-usual scenario is detailed in Section 4. The results are presented in Section 5. In the final section, discussion points raised out of the analysis are considered.

2 Theoretical framework

2.1 Border adjustment based on relative emission-efficiency

A price signal to differentiate agricultural commodities based on their relative emission-intensity when traded internationally is implemented by means of a Relative Emissions Border Adjustment (a REBA). The mechanism is used to reward countries that have achieved an international advantage in emission-efficiency and discourage trade of that commodity by relatively emission-intensive countries. A description of the framework follows for bi-lateral trade between the UK and the Rest of the World (RoW).

The price adjustment (tariff) is a function of emission-intensity (the units of emissions included per physical unit of output) and a scaling factor (*e.g.* emission price) to reflect the marginal external costs to society of each additional unit of emissions. For a commodity *i*, that is produced both inside and outside the UK, if imports of that commodity have a higher emission-intensity than for the same commodity produced domestically, imports will be subject to the tariff t_i^{UK} (Equation 1). In the opposite case, UK exports will be subject to the tariff t_i^{RoW} (Equation 2). The greater the disparity between UK and RoW emission-efficiency, the greater the tariff. The scaling factor v_i sets a price for each unit of relative emission-inefficiency[2].

$$e_i^{RoW} > e_i^{UK} \Rightarrow t_i^{UK} = \left(\frac{e_i^{RoW} - e_i^{UK}}{e_i^{UK}}\right) * v_i \qquad (1)$$

$$e_i^{UK} > e_i^{RoW} \Longrightarrow t_i^{RoW} = \left(\frac{e_i^{UK} - e_i^{RoW}}{e_i^{RoW}}\right) * v_i \qquad (2)$$

A notable feature of this approach is that a relative-emission-tariff at the border shifts the (national) comparative advantage towards agricultural commodities that are relatively emission-efficient in a *global* context. In this sense the global food supply can remain the same, while still achieving a reduction in global food emissions, because international trade has been used to improve the distribution of production activities globally from the perspective of emission-efficiency.

2.2 Global emissions

The expected impact on global emissions linked to the agricultural commodities included in a REBA is determined by accounting for the shift in production towards relatively less emission-intensive producers (holding global production constant and assuming all trade partners apply the REBA[3]). The

[2] Ideally, the scaling factor would reflect the cost to society of an additional unit of emissions, and so internalise the social cost of agriculture's methane and nitrous oxide emissions.

[3] The point is to isolate the efficiency gain from internalising global emission-efficiency comparative advantage. Holding overall production levels constant can also be described as assuming that the quantity consumed at a global-level remains constant (although the pattern of where that commodity is consumed can change). This provides a conservative result that is neutral with respect to the range of different contexts in terms of food security and diet change globally.

static impact on global emissions of a mechanism that shifts production towards the trade partner with better emission-efficiency in a bilateral one commodity case is shown in Equation 3.[4]

$$E_1^{global} - E_0^{global} = (e^{UK} - e^{RoW})(q_1^{UK} - q_0^{UK}) \tag{3}$$

Global emissions are lower after the implementation of a REBA ($E_1^{global} < E_0^{global}$) regardless of which trade partner has the emission-efficiency advantage, because if $e^{UK} < e^{RoW}$ (the UK holds the emission-efficiency advantage) then $q_1^{UK} > q_0^{UK}$ (production will shift away from the RoW towards the UK), resulting in a negative first term and positive second term. Conversely, if $e^{UK} > e^{RoW}$ then $q_1^{UK} < q_0^{UK}$, leading to a positive first term, but negative second term. The greater the disparity in emission-efficiency, or amount of displaced production, the greater the direct impact of the REBA on reducing global emissions for those commodities.

2.3 National emissions

National emissions 'by source' are the product of emissions per unit output and output summed over commodities produced.

$$E_{source}^{UK} = \sum_i e_i^{uk} \, q_i^{UK} \tag{4}$$

To calculate an indication of emissions 'by use' emissions embedded in imports are added to source emissions, and emissions embedded in exports are removed.

$$E_{use}^{UK} = E_{source}^{UK} + \sum_i (e_i^{RoW} \, m_i^{UK} - e_i^{UK} x_i^{UK}) \tag{5}$$

Accepting that in the case the UK has an emission-efficiency-advantage, and imports are subject to a tariff at the UK border, there will be a positive supply response in the UK of some amount, b_i^{UK}, then it follows that national 'by source' emissions related to that commodity will increase by $e_i^{UK} b_i^{UK}$. If the RoW has the emission-efficiency-advantage, with tariffs imposed on UK exports at the RoW border, then there will be a negative supply response of some amount, $-b_i^{UK}$, and so a reduction in associated emissions of $-e_i^{UK} b_i^{UK}$. The impact of the REBA tariff on the UK's emission inventory 'by use' however is ambiguous without knowing the degree of supply response (change in production levels) and trade response (change in imports and exports) [5]. If the magnitude of the UK's supply response exactly matches the trade response, then consumption emissions will decrease when it has the emission-efficiency-advantage (increasing production and reducing imports), and not change at all when the RoW has the advantage (reducing production and exports). If the supply response and trade response are asymmetric in magnitude, then UK emissions 'by use' can only be solved for numerically.

[4] Proof of how this is derived provided in the appendix.

[5] Proof provided in the appendix.

3 Methodology

To undertake the analysis the FAPRI-UK model (a collaboration between the Agri-Food and Biosciences Institute and the Food and Agriculture Policy Research Institute at the University of Missouri) is applied. The model is a partial equilibrium model of UK agriculture, projecting production, consumption, trade and producer prices for the main crops, livestock and dairy commodities for England, Wales, Scotland and Northern Ireland. The model is designed to project out 10 years, providing a medium-term outlook of the key variables. To determine how the agricultural sector in the UK interacts with external markets, the UK model solves simultaneously with a partial equilibrium model of the EU-27 (FAPRI-MU) that incorporates exogenously determined macroeconomic variables and global commodity price projections. A constant policy baseline projection is generated for the UK and EU models to provide a benchmark and is used as a point of comparison for scenario analysis. For each of the commodities in the model, the imports and exports are distinguished between the EU and RoW. This allows for separate tariffs to be applied in each of the trade equations and also allows for the application of the REBA in the model.

The FAPRI-UK model has been developed to include environmental indicators, allowing the for the calculation and projection of CH_4 and N_2O from agricultural activity. An 'emission factor' is calculated by allocating emissions from the GHG inventory (Harry Smith 2021) to the associated activity within the FAPRI-UK model. The volume of CH_4 emissions (generated from enteric fermentation and manure management) and N_2O emissions (generated from manure management and crop management activities) are divided by model variables (animal numbers and crop areas)[6]. The derived emission factors are expressed in kilotonnes carbon dioxide equivalent (kt CO_2 eq) per physical unit of model variable output (head, unit weight, or hectare). This generates a deterministic baseline projection of emissions 'by source'[7]. It is assumed that the emission factor for each subsector does not change over the projection period but is based on the reference year's published GHG inventory. This means that changes to emissions in the projection period are driven by productivity and production changes, not the introduction of emission-specific abatement technology or capture.

To incorporate 'embedded' emissions entering and leaving the UK *via* traded agricultural commodities, an emission-intensity is calculated by dividing the emissions for each subsector[8] by the production of the output commodity in the reference year. The emission-intensity is used as a benchmark to compare the emission-efficiency of agricultural commdoties between the UK and trading partners[9].

The FAPRI-UK model also projects a soil nutrient balance based on the inward and outward flows of nitrogen (N) and phosphorus (P) in feeds, fertilisers, crops, and livestock-derived commodities. In the case there is a larger inward than outward flow, the surplus of a nutrient in the system increases, which can be associated with risks to air and water quality. Therefore, this feature of the model

[6] For some emissions, there is not a direct activity in the FAPRI-UK model to map the GHG inventory emissions to. Assumptions were used to divide 'other cattle' emissions between dairy and beef. There are five commodity outputs in the model for dairy; liquid milk, cheese, butter, skim milk powder, and whole milk powder. A secondary allocation process is applied based on the estimated percentage of raw milk utilised to manufacture each dairy commodity.

[7] The projected emissions do not include all emissions from agriculture, as some agricultural sources are not included within the FAPRI-UK model, these include emissions generated from goats, horses, deer, stationary and off-road energy use in agriculture-forestry-fishing, and lubricants.

[8] Subsectors include wheat, barley, beef, sheepmeat, pig-meat, poultry, cheese and butter.

[9] In this research there is only one trading partner; the Rest of World (RoW)

provides an opportunity to anticipate potential environment-environment trade-offs as a result of the REBA mechanism.

To illustrate the impact of a REBA on UK agriculture and subsequently on national and global emissions, two scenarios have been implemented. In the first scenario, the UK is assumed to have the emission-efficiency-advantage (UK-EE-Advantage). This means that wheat, barley, beef, sheepmeat, pig-meat, poultry, cheese and butter are produced within the UK with a lower emission-intensity than the same commodity outside of the UK (in this case the Rest of the World, or RoW). The reference emission-intensity for producing a commodity in the UK is multiplied by 1.3 to reflect a stylistic assumption that a commodity produced in the RoW generates 30%[10] more emissions per unit. The second scenario assumes the reverse, that the commodity produced outside of the UK is 30% more emission-efficient than the same commodity produced in the UK (RoW-EE-Advantage). In this case, the reference UK emission-efficiency is multiplied by 0.7 to arrive at an assumed emission-intensity for the RoW.

[Table 1 about here]

The financial instrument used to disincentivise international trade of relatively more emission-intensive commodities is an *ad valorem* tariff. The tariff is set to 25% of the 5-year historic (UK) average price for that commodity (2016-2020). The rate is selected to illustrate the chain of effects, while staying within the limits of the modelling system, and does not reflect any actual or prospective policy recommendation.

[Table 2 about here]

The impact on global emissions is calculated based on Equation 3, UK emissions 'by source' based on change in quantities produced and the reference UK emission-intensity (Equation 4), and an estimate of the impact of the REBA on UK emissions 'by use' is calculated as the sum of 'by source' emissions and emissions embedded in imports less emissions embedded in exports (Equation 5). The emissions embedded in imports are adjusted depending on the emission-intensity of RoW commodities assumed in the scenario. This means there are two baselines of UK emissions 'by use', one for comparison with each scenario.

4 Results

4.1 Global emission impacts

Within the simplified two-country application of a REBA global emissions from the commodities subject to the tariff are lower in both the UK-EE-Advantage and RoW-EE-Advantage scenarios than in the business-as-usual projection. Emissions from cheese, beef, and sheepmeat production see the largest reductions in the UK-EE-Advantage scenario. In the RoW-EE-Advantage scenario sheepmeat and beef are amongst the commodities with the largest reductions, as well as wheat and barley. Across all commodities modelled, sheepmeat, beef and cheese are the most emission-intensive commodities (according to the system boundary and method applied in this analysis). Therefore, a relatively small shift in production, can generate a comparable global emission-impact as a much more extreme production shift in poultry, pigmeat and cereals, which exhibit the lowest emission intensities.

[10] A 30% difference was selected to generate a large enough impact to observe how the REBA impacts emissions. It does not reflect any assumptions about the actual difference in emission-intensity between the UK and other producers.

[Figure 1]

4.2 National impact

The REBA tariff impacts UK agriculture *via* prices. In the UK-EE-Advantage scenario imports become relatively more expensive, and the balance of trade leads to an increase in UK prices. In response to higher domestic prices, production volumes, and domestic use of cereals to fuel additional livestock production, are above business-as-usual levels while domestic use of livestock commodities are below... UK emissions from production ('by source' emissions) increase in the UK-EE-Advantage scenario. This is because, in this scenario, the UK enjoys an *international* emission-efficiency advantage in all commodities. Therefore, the REBA tariff does not incentivise only those UK commodities with a *national comparative* emission-efficiency advantage (so, for example, UK chicken is not favoured over UK sheepmeat, as would have been the case if the price instrument was based on absolute emissions, instead of relative emissions). This result illustrates how the REBA method operates to reduce global food system emissions (*ceteris paribus*) rather than national emissions. This pathway of impact does, nevertheless, reduce 'by use', or consumption emissions (combination of imports and domestic production), for the UK. This is because a larger share of domestic commodities are consumed which have a lower emission-intensity than their imported counterparts.

In the RoW-EE-Advantage scenario, a tariff is charged on UK exports leading to a general reduction in UK prices. Domestic production decreases, but not to the full extent that exports decrease (following the reduction in international price competitiveness). Somewhat counterintuitively, this scenario leads to additional supply of UK produce in the domestic market (as exports are no longer competitive in RoW). Lower prices contribute to a general increase in domestic use, except wheat for feed use, which decreases (in line with the reduction in livestock production). The downward pressure on UK production leads to a corresponding decrease in related emissions in the RoW-EE-Advantage scenario. However, the dynamics of the supply response result, as with the previous scenario, in a larger share of domestic produce consumed within the UK. In this case, the displaced exports have the lower emission-intensity, and so UK consumption emissions increase.

[Table 3 about here]

The impacts of the REBA on the UK's domestic markets and emission-inventory are largely driven by the relative magnitudes of the production response and the trade response. An indicator of symmetry between the relative change against the business as usual when the REBA is implemented is calculated as the natural logarithm of the absolute value of the ratio between the production response and trade (net exports) response. The closer the indicator is to zero, the more symmetric the magnitude of the two responses to the REBA (compared to business as usual). The UK's trade response in wheat is much stronger than its production response in the UK-EE-Advantage scenario but is relatively symmetric in magnitude in the RoW-EE-Advantage scenario. Beef and sheepmeat exhibit an asymmetric response in the first few years of REBA implementation that is a result of the inclusion of livestock dynamics in the model. An increase in returns for beef, sheepmeat (and dairy) results in animals that would have been slaughtered being retained for the breeding herd. Thus, short run behaviour can be different from longer run behaviour in these sectors.

[Table 4 about here]

[Figure 2 about here]

As expected, due to the increase in livestock-based production, in the UK-EE-Advantage scenario the surplus of nitrogen and phosphorus in the UK increases. Livestock numbers increase and the area for grains also increases very marginally due to the increase demand for grains for animal feed. Both imports and exports of grains decrease as domestic use increases (UK self-sufficiency increases). This causes a net additional surplus of nutrients at a UK level.

In the RoW-EE-Advantage scenario there is a decrease in the surplus of nitrogen and phosphorus in the UK agricultural system. This is because the negative supply response of livestock-derived commodities, reducing imported feed, outweighs the reduction in exports, resulting in a net improvement in the system balance.

[Figure 3 about here]

5 Discussion

Results indicate that regardless of whether the UK, or the trade partner, enjoys the emission-efficiency-advantage, global emissions reduce under the REBA mechanism, due to the trade-system incentivising the production to shift to the more emission-efficient trade partner. The potential trade-offs, as illustrated here with the case of the UK, include relatively higher domestic prices for meat and dairy, national emissions from agriculture, and N and P imbalances. is an increase in national emissions and worsening of nutrient imbalances. This is because, the mechanism incentives trade-partners to specialise in commodities in which they have an *absolute* emission-efficiency advantage (internationally). However, these may not be the same commodities for which they have a *comparative* emission-efficiency-advantage domestically. This finding makes sense in the context of the wider literature on carbon leakage that has found global emission reductions are more likely to be driven by technical efficiencies rather than reducing carbon leakage in and of itself. Annalysis of border adjustments targeting CH_4 and N_2O emissions from agriculture have shown that production displacement or 'leakage' is a major drawback when emissions are taxed, even when this tax is extended to imports, with any reductions in global emissions driven by the adoption of 'greening' measures, to improve the emission-efficiency of production (Himics, Fellmann et al. 2018). An evaluation of the EU's Carbon Border Adjustment Mechanism (CBAM), shows that avoiding 'leakage' is a necessary but not sufficient condition to reduce global emissions, as major suppliers to the global market may not have national policy or resourcing to drive reducing emissions-intensity (Tarr, Kuznetsov et al. 2023). The indirect effects of a policy specifically targeting carbon leakage in agriculture, however, could still be considerable by improving the political and economic viability of taking on ambitious action to reduce the environmental pressures of the food system.

The issue of carbon leakage is closely linked with the difficulties associated with global-level free riding with respect to GHG mitigation (Paola Rocchia 2017). Here as well there is a national trade-off to be acknowledged. A REBA-type mechanism, if applied broadly enough within the global economy, would reduce the pay-off from excluding emissions in strategic plans and policies to maintain or improve cost competitiveness internationally. However, because it is based on national average emissions, such a mechanism would *not* directly motivate firm-level improvements in emission-efficiency. Even so, it *could* motivate national initiatives in the public and private sector to improve emission-efficiency (by food exporting companies for at least part of the farm production base).It is important to consider that because the REBA targets internationally traded goods, the more thinly a commodity is traded internationally, the less likely the price signal from the tariff will impact production and/or consumption nationally, even if that commodity has a large environmental footprint.

There are also strengths associated with using a national average emission-intensity to determine the relative efficiency between trading partners. Practical viability has been highlighted as one of the biggest barriers to internationally harmonised carbon pricing in the energy-intensive sphere

(Böhringer, Fischer et al. 2022). Linking the REBA to the existing international reporting reduces the initial investment in establishing a complex framework for measuring, auditing, and updating emission-efficiency, that is accepted internationally. Within the Intergovernmental Panel on Climate Change (IPCC), a system is already in place to validate and progress inventory calculations to more nuanced emission factors at the national or sub-national level (the Tiered approach) (IPCC 2006, IPCC 2019). A positive feedback effect of a REBA could be increased investment by mulit-national corporations with international supply chains to improve data collection and public institutions in order to help progress a larger proportion of countries from more general (Tier I) emission factors, to more accurate factors, motivated by improved competitiveness in international markets (*via* lower REBAs).

Another important consideration when discussing the potential benefits and drawbacks of a REBA-type mechanism for agriculture is what we measure, as well as, how targets are defined and progress evaluated. In the example illustrated here, the REBA improves the UK's position with regard to either production emissions (those considered to measure progress towards GHG reduction targets) or consumption emissions (those reflecting the emissions-responsibility of the end user) but not both at the same time. Targets tend to be defined and measured against reducing production emissions to some proportion of a historic baseline. The National Atmospheric Emissions Inventory publishes an 'end user' allocation of GHG emissions {Lucy Garland, 2023 #19} but this still only applies to emissions generated within the geographical boundary of the UK. There are understandable challenges with accurately measuring and tracking the flow of emissions embedded in goods and services. Although not as comprehensive as other accounting frameworks (such as though capturing impacts from cradle to grave) a key benefit of a simple relationship between reported emissions to the IPCC, and a national average emission-intensity for internationally traded commodities, is that it is transparent, and if applied consistently across reporting countries, can be combined with trade-data to facilitate a more accurate representation of consumption-based emission responsibility in the global food system.

There are also concerns around global and national food supplies. This is in part because there are complex nutritional and non-GHG environmental trade-offs of changing the input and/or output mix of agriculture. In the case of electricity, it has been shown that a small open economy can avoid 'leakage' by taxing fossil-fuel-derived electricity at a lower rate while simultaneously subsidising renewable-derived electricity (Kruse-Andersen and Sørensen 2022). This can work in the energy sphere because renewable-derived and fossil-fuel-derived electricity are perfect substitutes at the point of final consumption. In the case of agriculture, this type of tax/subsidy model is more problematic due to the likelihood of triggering resistance *via* World Trade Organisation agreements. International trade is a powerful force in the food system. It has allowed countries to specialise production and diversify consumption. This force can be better utilised to generate positive outcomes for society if environmental, as well as economic, efficiencies are internalised. A REBA-type mechanism could be a useful addition to a wider policy portfolio by reducing the impacts of leakage and reconciling domestic policy with global emission objectives while minimising the impact on food security.

6 Conclusions

Many countries have ambitious targets reducing GHG emissions over the coming decades. The agriculture sector, which for some countries is often a significant contributor to emissions, has been part of the policy discussion. Up to now much of that discussion has focused on taxing either production or consumption within a country. While this can theoretically be targeted directly at emission-levels, studies often show significant issues with carbon leakage, and there can be food security implications. Policies that focus on domestic industry will not necessarily take into account the impact on global emissions. Thus, a country that has a large agricultural sector might seek to reduce emissions from that sector even if that sector is relatively efficient with regard to emissions globally.

A way to address these challenges is to implement a border adjustment. Interest in these types of measures has increased to protect trade-exposed domestic industries being undercut in terms of cost competitiveness, in order to meet national emission requirements. In this paper, a hypothetical border adjustment mechanism for agricultural commodities is developed. Adjustments are made at the UK border within a partial equilibrium model to provide an illustrative example of what may happen to global emissions and UK agriculture. The results show the complexity of the issue. The REBA improves the alignment of domestic emission targets with global emissions. However, the policy is less aligned with domestic emission reduction objectives. We found that when the UK is relatively efficient globally in production, there is likely to be an expansion in production and therefore an increase in national emissions. Where the UK is relatively inefficient with regard to emissions, domestic prices fall (as exports markets close) and emissions associated with consumption in the UK can increase (although emissions from UK production fall from levels found before the introduction of the REBA).

This paper illustrates how international trade can be a vehicle to reward and promote global emission-efficiencies, reducing the average emission-intensity of agricultural commodities, and thus global agricultural emissions, without necessarily reducing global consumption. The simulation analysis demonstrates some interesting and counter-intuitive outcomes. Global emission-efficiency gains could come at a cost to UK-level GHG reduction targets, either *via* increased emissions from domestic agricultural production (if the UK has an international emission-efficiency advantage) or *via* increased emissions embedded in domestic food consumption (if the UK has the emission-efficiency disadvantage). These findings illustrate the potential benefits of implementing harmonious climate policies in order to accelerate GHG reductions in a manner that is consistent with underlying economic efficiency of production. It is likely that a combination of policies for agricultural emissions are required if countries are to meet net zero targets.

Table 1. Reference UK emission-intensity in kiloton CO_2 equivalent and assumed emission-intensities outside of UK imposed in the scenario analysis

Commodity	United Kingdom average	Rest of World:UK-EE-Advantage	Rest of World:RoW-EE-Advantage
Sheepmeat	13.71	17.82	9.60
Beef	11.82	15.37	8.27
Cheese	7.14	9.28	5.00
Butter	1.6	2.08	1.12
Pigmeat	1.06	1.38	0.74
Barley	0.48	0.62	0.34
Wheat	0.42	0.55	0.29
Poultry	0.17	0.22	0.12

Table 2. Historic (five year) average price and REBA tariff (£ per tonne)

Commodity	Historic average price	REBA tariff
Cheese	2,835	708
Butter	3,614	903
Beef	3,446	861
Sheepmeat	4,306	1,076
Pigmeat	1,484	371
Poultry	1,527	381
Wheat	159	39
Barley	130	32

Figure 1. Emissions avoided (holding global consumption constant) by shifting production towards the more emission-efficient trade partner (kilotonnes CO_2 equivalent of methane and nitrous oxide)

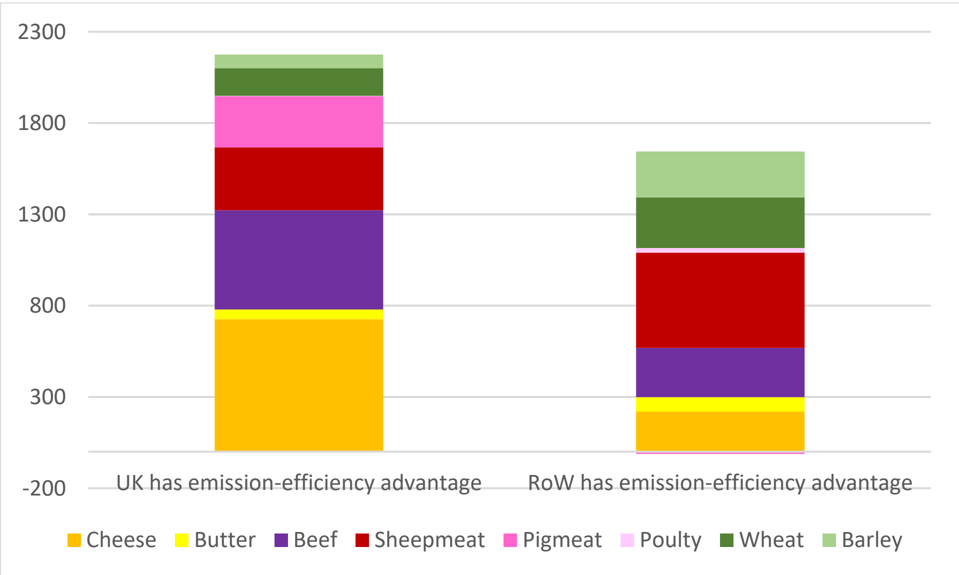


Table 3. Percentage difference in prices, production, and domestic use (with and without a REBA tariff)

	UK emission-efficiency-advantage					RoW emission-efficiency-advantage				
	Price	Production	Domestic use	Feed use	Food use	Price	Production	Domestic use	Feed use	Food use
Wheat	4.2	0.8	1.0	2.9	-1.1	-7.4	-1.6	0.4	-1.4	2.6
Barley	3.6	0.7	2.2	3.4	-0.1	-12.9	-2.4	0.6	0.7	0.5
Beef	7.5	1.8	-2.1			-9.5	-0.9	3.0		
Sheepmeat	5.5	3.0	-1.0			-11.9	-4.5	2.1		
Pigmeat	12.8	10.3	-3.7			-1.9	-0.2	0.5		
Poultry	1.6	0.2	-0.3			-8.1	-2.4	1.4		
Cheese	15.7	7.0	-2.4			-6.3	-2.1	1.1		
Butter	4.1	5.9	-1.2			-15.7	-8.7	5.1		

Table 4. Indicator of symmetry between production and trade response (0 = perfectly symmetric)

	UK emission-efficiency-advantage										RoW emission-efficiency-advantage									
Commodity	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Wheat	-0.5	4.2	1.5	1.3	1.2	1.2	1.1	1.1	1.1	1.0	-0.6	-0.2	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3
Barley	0.1	-0.5	-0.5	-0.4	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-1.0	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Beef	-1.5	-1.2	-2.9	-1.4	-0.8	-0.6	-0.5	-0.5	-0.5	0.4	-1.1	-1.8	-4.1	-2.6	-2.1	-1.8	-1.5	-1.3	-1.1	-1.0
Sheepmeat	0.6	-2.9	-0.3	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	0.9	-3.3	-0.7	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.2
Pigmeat	-1.7	-0.7	-0.5	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-1.6	-0.7	-0.8	-1.2	-1.7	-2.2	-4.1	-3.0	-2.7	-3.0
Poultry	-0.2	-0.7	-0.7	-0.9	-1.0	-1.0	-1.1	-1.5	-2.6	-3.7	-0.2	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Cheese	-0.8	-0.5	-0.5	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.5	-1.2	-0.5	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Butter	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

Figure 2. Difference in UK emissions between REBA scenarios and the business-as-usual projection (kilotonnes CO_2 equivalent)

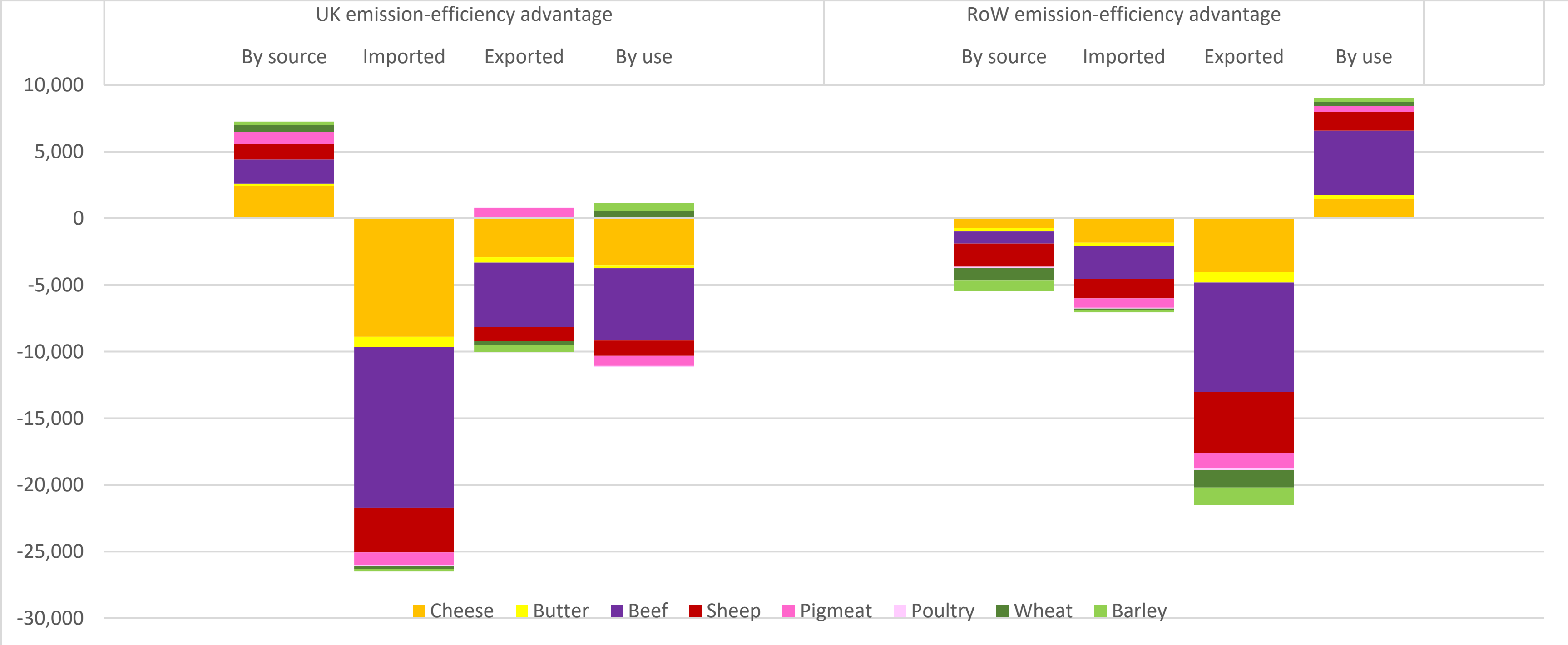
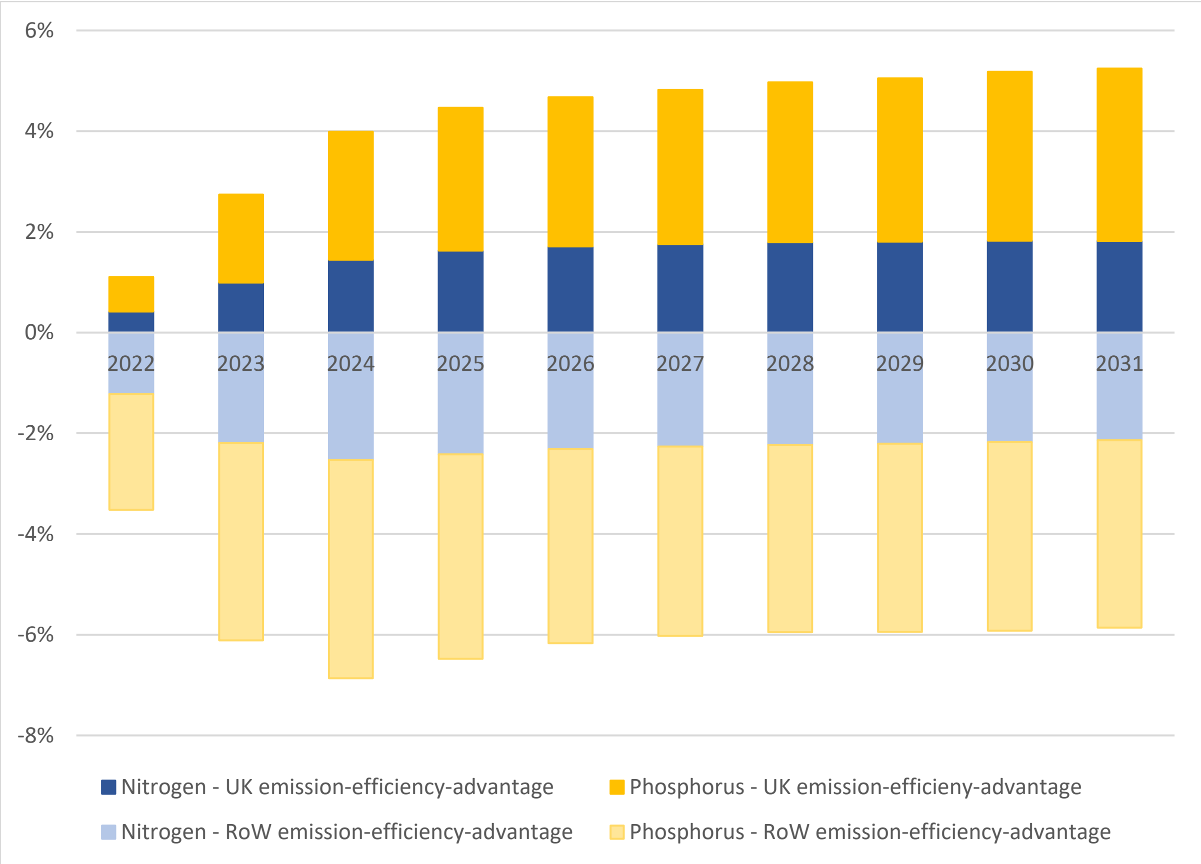


Figure 3. Percent difference in the UK's nitrogen and phosphorus nutrient surplus with and without a REBA mechanism



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A. Appendix

Global emission impact

Emissions in scope of the REBA are defined as the emissions per unit of production output times the quantity of output produced. Summed across trade partners provides the global level of emissions.

$$E_0^{global} = e^{UK} q_0^{UK} + e^{RoW} q_0^{RoW} \quad \text{(A-1)}$$

The impact of the REBA on global emissions is determined by the difference in the quantity of output produced (as emission-intensity is assumed to be the same).

$$E_1^{global} - E_0^{global} = e^{UK}(q_1^{UK} - q_0^{UK}) + e^{RoW}(q_1^{RoW} - q_0^{RoW}) \quad \text{(A-2)}$$

Global consumption (production) is assumed to be constant.

$$Q^{global} = q_0^{UK} + q_0^{RoW} = q_1^{UK} + q_1^{RoW} \quad \text{(A-3)}$$

Therefore, RoW production can be expressed as a function global production and UK production and substituted into Equation A-2.

$$E_1^{global} - E_0^{global} = e^{UK}(q_1^{UK} - q_0^{UK}) + e^{RoW}(q_0^{UK} - q_1^{UK}) \quad \text{(A-4)}$$

If we define $q_1^{UK} - q_0^{UK} = b$, then $q_0^{UK} - q_1^{UK} = -b$, and so A-4 can be re-written to illustrate the change in global emissions depending on the difference in emission-intensity, and the amount of production that is shifted.

$$E_1^{global} - E_0^{global} = (e^{UK} - e^{RoW})b \quad \text{(A-5)}$$

National emission impact

Let production in the UK increase and imports decrease by some amount b_i^{UK} so the use emissions related to product i will be $E_{use,i}^{UK} = E_{source,i}^{UK} + e_i^{UK} b_i^{UK} + e_i^{RoW}(m_i^{UK} - b_i^{UK})$, and the change in use emissions will be $\Delta E_{use,i}^{UK} = (e_i^{UK} - e_i^{ROW}) b_i^{UK}$, so because $e_i^{UK} < e_i^{ROW}$, we know that $\Delta E_{use,i}^{UK} < 0$.

UK climate policy background

The UK government and devolved administrations have committed to reducing GHG emissions to 'net zero' by 2050 (National Audit Office 2023). This means that the UK will have to reduce its GHG emissions by 100% of 1990 levels by the year 2050. The 1990 baseline is used as a target so that the amount of GHG emissions produced by the UK would be equal to or less than the emissions removed from the environment (House of Lords Library 2023). This allows some sectors to continue emitting GHGs, to the extent that carbon sequestration and removal in the wider economy create headroom while satisfying the net zero condition. The UK was the first major economy to pass a net zero emissions law which was made legally binding by the Climate Change Act 2008.

As well as a net zero target of 2050, the UK Government has set an interim target of reducing carbon emissions by 68% by 2030 and a further target of reducing carbon emissions by 77% by 2035 compared to 1990 levels. The four nations within the UK will collaborate to achieve the UK level target, although Scotland, Wales and Northern Ireland have separate legislation and pathways on GHG emission reductions. Industry within each of the four nations varies and therefore each nation face different challenges to reach net zero. For example, the highest emitting sectors in Northern Ireland and Scotland is agriculture and transport. Whereas, the highest emitting sector in Wales is energy supply and business.

In most industries in the UK, CO_2 is the primary GHG emitted, whereas in agriculture, methane (CH_4) and nitrous oxide (N_2O) are the main sources of GHGs (Department for Environment Food and Rural

Affairs 2022). Due to the different production systems used, GHG emissions vary significantly between farming sectors.

In a similar approach to the UK Government, each devolved region has set interim targets before the 2050 deadline. Wales, Scotland and Northern Ireland have created their own laws, whereas England will consider its progress alongside the other 3 nations under the Climate Change Act 2008. A common theme in each of the devolved nation's action planning includes improving land management practices. Northern Ireland is the only country to include an alternative target for methane emissions in their Climate Change Act (Northern Ireland Assembly 2022). This target does not require methane emissions to be reduced by more than 46% of the 1990 baseline.