Adjusting for agricultural greenhouse gas emissions at the UK border: an illustrative analysis

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The 2021 baseline uses global prices from the FAPRI-MU global system of models. The UK level data is taken from the Department for Environment, Food and Rural Affairs. Other data for England, Wales, Scotland and Northern Ireland has been taken from the relevant government websites.

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Executive summary

Greenhouse gas (GHG) emissions are transboundary. Therefore, associated impacts to the climate system depend on the volume of global emissions in the atmosphere, regardless of where the emissions were generated. However, GHG mitigation policies are determined at national level, address national priorities and proceed at different speeds. As a consequence, efforts to cut emissions in one place, can be counteracted by an increase elsewhere. International trade can exacerbate this problem by displacing domestically produced goods with imports. If at least the same amount of emissions were generated producing the good abroad, compared to if it had been produced domestically, then emissions have been 'exported' rather than 'abated'. This displacement of emissions *via* international trade is known as 'carbon leakage' and is a major concern for producers and policymakers seeking to establish GHG reduction pathways for agricultural commodities.

Policy Challenge

Implementing national initiatives and standards to reduce emissions per unit of output can reduce production costs, for example *via* efficiency gains or (in contrast) add expense through higher compliance costs. In some situations, fulfilling GHG reduction targets could simultaneously improve emission-efficiency (GHGs per unit of output produced) but reduce economic-efficiency (cost per unit of output produced). This can lead to first mover disadvantage when implementing GHG mitigation policies in markets not subject to a common GHG reduction framework. If not addressed, this could give rise to carbon leakage because national production becomes less competitive in domestic and international markets, with negative impacts for terms of trade, and no reduction in global GHG emissions. One way to address the problem of carbon leakage between trading partners is to charge for higher carbon content via a border levy. The EU has introduced such a framework in the form of the Carbon Border Adjustment Mechanism (CBAM). Such schemes work to incorporate the costs of carbon in trade and provide incentives to both domestic and foreign producers in a market to lower the GHG intensity of goods.

Research Question

This report presents an illustrative analysis of the various potential impacts of implementing a Greenhouse Gas Emission Border Adjustment (GEBA) on the main agricultural commodities at the United Kingdom (UK) border. The methane and nitrous oxide emissions embedded in each unit of output produced in the UK is estimated, standardised as carbon dioxide equivalent units (CO_2eq), and used as a point of reference. This allows emissions embedded in goods crossing the border (imports and exports of the same commodity) to be estimated and analysis undertaken to illustrate the impact of a tariff on UK output, imports, exports and prices, for selected agricultural commodities, when UK emission intensity is higher or lower than that of a trading partner. The tariff is only applied on the commodity with the higher emissions intensity per unit of product.

The emission-intensity of agricultural commodities is introduced into the FAPRI-UK Modelling System to project a baseline production (source) emission inventory out ten years. This allows comparison of both economic and emission impacts for a series of scenarios. These include:

- assuming the UK has a relatively lower emission-intensity than the same commodity imported from abroad (an advantage in emission-efficiency) that is reflected by imposing a penalty on imports at the UK border (as an *ad valorem* tariff), and,
- assuming the UK has a relatively higher emission-intensity (a disadvantage in emission-efficiency) that means UK exports face a tariff on entry to foreign markets.

Finding One

In the case the GEBA tariff is imposed on imports to the UK (because the UK has lower emissions per unit of commodity produced) it protects domestic producers compared to the baseline, imports and exports decrease, and domestic production increases marginally (along with prices). The increase in domestic production leads to more UK production (source) emissions than without the GEBA intervention. Consumption (use) emissions, however, are lower in the case of a GEBA than they would be otherwise, because relatively more emission-intensive imports are displaced by their relatively less emission-intensive domestic counterparts. In other words, the UK is importing fewer emissions. Assuming there is no difference in global consumption/production of agricultural commodities, the global volume of methane and nitrous oxide is lower when a GEBA is imposed. This is because the increase in UK production displaces more emission-intensive production that would have occurred outside the UK. However, as UK emissions (as measured by the source inventory method) increase, progress to reduce aggregate national emissions is hindered unless a border adjustment on high emissions imports is accompanied by policies that reduce the emissions intensity of UK production.

Finding Two

In the case the GEBA tariff is imposed on UK exports (because the UK has higher emissions per unit of commodity produced) it results in an overall decrease in domestic agricultural production compared to the baseline because exports are less price competitive and export volumes decline. However, domestic production takes a larger share of domestic consumption (at a lower price), and imports decrease (compared to the baseline). In this scenario, as overall UK production decreases, total UK emissions (as measured by the source inventory method) decrease, and progress to reduce aggregate national emissions is helped. In contrast, UK consumption (use) emissions increase, because fewer emissions are being 'exported' from the UK, leading to the average emission-intensity of the commodity consumed domestically being higher under a GEBA compared to the baseline. This is because of the larger share of relatively emission-intensive commodity that is sourced domestically.

Finding Three

The scope of the agricultural commodities subject to a GEBA is also varied across scenarios. In line with results described in Finding One, when the GEBA tariff is imposed on imports to the UK of a livestock-derived commodity, the price for that commodity increases along with UK production, and domestic use declines compared to the baseline. However, in contrast to this outcome, UK domestic use increases in the case of cereals, even when cereal imports to the UK are subject to a GEBA tariff. This occurs because of the increased UK demand for animal feed associated with additional UK livestock production when livestock-derived imports are also subject to a GEBA tariff. It increases use of both UK and imported cereals for animal feeds, along with imports of soymeal, and could have negative implications for environmental policies other than GHG reductions, such as improving water quality by maintaining or improving UK nutrient balances. The increased environmental pressures arise from the production of more animal manure and its application to farm land.

Finding Four

A GEBA tariff applied to UK commodity exports (livestock-derived and cereals) to foreign markets decreases UK prices and overall UK production, but increases UK use of domestically produced commodities, as some imports to the UK are displaced. However, if tariffs are applied to only a subset of agricultural commodities, for example, when livestock-derived commodities exported from the UK are subject to the tariff, but UK cereal exports are not, domestic use of cereals decreases instead. This is due to lower production levels in the livestock sector (decreasing feed demand) combined with no disincentive (GEBA tariff) to UK cereal exports. Although UK exports decrease (and in contrast to the scenario described in Finding Three), this results in a reduction in UK crop and livestock production compared to the baseline and has complementary impacts for nutrient balances, leaving these below the baseline level.

Final remarks

The analysis is illustrative but provides a vehicle to explore, in the context of UK agriculture, the impacts of intervening to discourage the movement of emissions embedded in commodities across borders. The results succeed in illustrating a number of issues, relevant to interventions that attempt to internalise emission-intensities within international competitiveness.

The GEBA inhibits carbon leakage (production moving from lower to higher emitting international competitors) and leads to a decrease in the global volume of emissions. It encourages production in the UK when it can produce a given commodity with relatively better emission-efficiency, and elsewhere when it cannot. However, this means that production (source) emissions are higher in the UK when it has a competitive advantage in emission-efficiency, while consumption emissions will be lower than the baseline level. The opposite is true when the UK is relatively less emission-efficient, with production emissions lower than baseline levels, but consumption emissions relatively higher.

The impact on the UK agricultural source emission inventory would depend on the aggregate emissions efficiency of all domestically produced agricultural commodities that are also internationally traded. This has implications for how emission-reduction targets are defined, accounted for, and progress is evaluated. This analysis assumes average national emission-intensities are the same for the entire ten year projection period. However, if there was a movement towards greater convergence, or divergence, between the UK and RoW in terms of emission-intensity, then the costs and benefits to UK producers and consumers would change, as would the implications for source or use accounting frameworks in the UK emissions inventory.

Regardless of whether the UK is relatively more or less emission-efficient than the trading partner, the GEBA ultimately has a positive influence on emissions reduction – although the costs and benefits from changes apply unequally on producers or consumers. Consumers benefit from lower prices when UK exports are subject to the GEBA tariff, and although production does decline, increases in import volumes is dampened because some domestic supply is redirected from exports to meet UK demand. In the case when the GEBA tariff falls on imports, producers enjoy higher prices, and a stronger position in the domestic market. The potential interaction of protecting the domestic market can complement, or hinder, national emission reduction strategies, and would need to be considered carefully in the wider policy context.

A GEBA works against carbon leakage from the UK by avoiding substitution by the same commodity produced elsewhere – but with more embedded emissions. It also works in the opposite direction, discouraging UK production of high emissions-intensive exports from the UK. The application of this framework provided in this report does not vary the emission or tariff border adjustment across commodities. Therefore, the GEBA tariff itself does not change consumption/production to favour less emission-intensive commodity types, and price levels may adjust to maintain the competitiveness of domestic production in the UK market. This means changes to consumption and production patterns are driven by the UK's new trade position, which incorporates international carbon competitiveness. In this way, international trade can support national action to reduce emissions by reducing first mover disadvantage, as well as incentivising trade partners to do the same.

1. Introduction

Greenhouse Gas (GHG) emissions reduction ambitions have increased as climate science has demonstrated the need for urgent action. In response, the UK Government has established a net zero carbon target for the country by 2050[1], and demanding national targets are also in place for Scotland, Wales and Northern Ireland.

GHG emissions from the agriculture sector account for about 10% of the total GHG emissions in the UK (inventory year 2019). Agriculture was the source of 68% of total nitrous oxide emissions, 47% of total methane emissions and 1.7% of total carbon dioxide emissions[2]. Also, each nation within the UK has a part to play in reducing GHG emissions as England, Wales, Scotland and Northern Ireland contributed 60%, 12%, 16% and 12% respectively to total UK agricultural GHG emissions in 2019.

To meet the targets outlined, agriculture will have to make a substantial contribution but it faces some unique challenges. First, it is difficult to measure and monitor emissions when the biophysical nature of the main sources are subject to variation. The structure of the industry is also highly fragmented (unlike electricity generation which is a highly concentrated sector). However, food is similar to energy in at least one respect, in that national interests in security of supply exist. This can lead to sensitivities around actual and perceived changes to self-sufficiency or related food security. Similarly, narratives around helping to meet growing global demand for food can influence how changes in the food system are perceived. Finally, there is no current international framework in which to co-ordinate an efficient and equitable reduction in GHG emissions from agricultural production.

In the UK, industry is cautious about emission reduction proposals that will increase costs and potentially displace production to countries that have lower costs but also generally lower environmental standards. When domestic production of a commodity is displaced by imports, this is referred to as 'carbon leakage' because essentially the UK has transferred some of its production emissions elsewhere. In these circumstances, there may be no reduction in the volume of global GHG emissions driving climate impacts, while any costs associated with the changes are born within the UK. As barriers to international trade in agricultural products reduce because of bilateral and multilateral agreements, this problem may be expected to become a more significant consideration. Likewise, if a commodity can be imported to the UK with a relatively lower impact on global emissions, there could be climate benefits from discouraging domestic production and encouraging imports of that commodity.

In terms of possible interventions, from an economic perspective it is desirable to reduce emissions in a way that is cost-effective, keeping in mind the welfare impact of those costs across society. This requires a range of interventions far beyond the capacity of any one policy instrument in isolation. Therefore, this analysis explores the potential impacts of a single instrument with a single and specific purpose: to address the potential for carbon leakage *via* international trade. In this case, by imposing a price disadvantage on imports that are relatively more emission-intensive than their domestically produced counterpart.

This report investigates the potential impacts of an illustrative GHG emission border adjustment to further understand the effects of such policy tools on emissions reductions and displacement (carbon leakage) in the context of domestic agriculture. The model developed here is preliminary

[1] UK Net Zero Strategy – Build Back Greener (19 October 2021)

[2] Agri-climate report 2021 - GOV.UK (www.gov.uk)

and stylised but is an effective first step in illustrating some possible effects (under strong but transparent assumptions) on UK production, imports, exports and commodity prices of introducing an *ad valorem* tax on UK international trade as a means of enabling such a border adjustment. The tax is applied to imports to the UK that have higher embedded GHG emissions than UK domestic production in the same commodity, and to exports from the UK that have higher embedded GHG emissions than that same commodity produced by the trading partner. Such a policy is a logical first step in reducing the GHG impact of consumption, as it avoids highly regressive taxes on food consumption, encourages food production in the UK in commodities where there is relatively lower GHG emissions than elsewhere; and helps prevent displacement of production to countries with higher GHG emissions per unit of production.

To explore the potential implications of applying a GHG Emission Border Adjustment (GEBA) to agricultural commodities in the UK, a series of hypothetical scenarios are implemented within the FAPRI-UK Modelling System (a collaboration between the Agri-Food and Biosciences Institute, and, the Food and Agriculture Policy Research Institute, University of Missouri, supported by Defra, the Welsh Government, Scottish Government, and DAERA in Northern Ireland). These scenarios consider the impact on UK national source (e.g. production) and use (e.g. consumption) methane and nitrous oxide agricultural emissions, production, prices and trade flows when the relative difference of GHG emissions embedded in a traded commodity is adjusted for at the border, projected forward to the year 2031. Specifically, the direct and indirect impacts of changes to the UK's international competitiveness when a UK commodity is relatively emission-efficient compared to trade partners, and also when it may be less relatively emission-efficient. The relative emission-efficiency is based on the difference in emission-intensity for the same commodity on both sides of the border. It does not (dis)incentivise across different commodities based on their relative emission-(in)efficiency. In this way, there is one instrument with one distinct purpose, to work against 'exporting' emissions, and generating an advantage in emission-efficiency that can be reflected in international trade.

2. Conceptual framework

The GEBA is conceptualised as a price-adjustment at the border, based on relative emission-intensity of a traded product. The intention is to directly address unwanted GHG-emission-leakage *via* international trade[3]. The adjustment hinges on relative, as opposed to absolute, emission-intensity. Therefore, the mechanism has the potential to take advantage of trade connections and flows, to encourage agricultural producers, both domestic and foreign, to reduce the GHG intensity of agricultural commodities. This can potentially reduce the global volume of GHG emissions, because the same trade channels that potentially encourage GHG 'displacement' are instead used to 'redistribute' production to the most GHG efficient supplier.

2.1 Greenhouse gas emission border adjustment application

Within this set of scenarios the adjustment at the border is based on the relative GHG emission-intensity of UK domestic production, compared to that of the trade partner, for simplicity taken here as the Rest of the World (RoW). The UK is the point of reference, and the GEBA adjustment is based on whether the RoW is assumed to have either a higher or lower emission-intensity for the same commodity produced in the UK. Emission-intensity is defined here as the quantity of GHG emissions generated for each physical unit of output. Allocating emissions generated as part of the primary production process (source emissions) to a physical amount of output, is a way to 'embed' those emissions so that they 'travel' with the commodity to the market where it is ultimately consumed. This approach allows for differences in emission-intensity between trade partners to be explicitly addressed at the border. In addition, GHG emissions associated with the consumption of agricultural commodities in the UK (use emissions) can be estimated based on UK demand met by a combination of domestic supply, imports, and their respective emission-intensities.

Let x represent the physical quantity of commodity i produced domestically, and E the physical amount of (source) emissions associated with producing quantity x of commodity i (e.g. those recorded in the published GHG emission inventory). The emission-intensity per unit of commodity i is defined as the emissions per unit of output, or e_i.

$$e_i = {}^{E_i}/_{x_i} \tag{2-1}$$

The difference in emission-intensity of commodity i between two trading partners is defined using a relative efficiency approach. One trading partner, in this case the UK, is used as the reference emission-intensity. The relative emission-efficiency is the distance (as a proportion) between the reference (UK) and the trade partner (RoW). If there is no difference between e_i^{UK} and e_i^{ROW} there is no need to adjust for emissions at the UK border, and so a_i^{UK} is zero. When emission-intensity is lower for commodity i in the UK than the RoW, this means that the UK is more emission-efficient in i. Therefore, an adjustment is needed to account for the additional emissions per unit crossing the border into the UK. If the UK is less emission-efficient in commodity i than the RoW, the adjustment will be negative, to account for the fact that fewer emissions per unit of i cross into the UK from the RoW.

$$a_i^{UK} = \frac{(e_i^{ROW} - e_i^{UK})}{e_i^{UK}} \tag{2-2}$$

[3] The instrument described here targets carbon leakage specifically – it is based on how efficiently a given commodity can be produced under different systems and contexts (in this case aggregated to a national average). It does not penalise some commodities over others, as would be the case with a carbon tax, taxing per unit of absolute emissions.

A numerical example can help illustrate how the relative emission-efficiency translates into an emission, and price adjustment. In the case that the RoW generates 130 units of emissions per unit of output, and the UK only generates 100 units of emissions, it can be said that the UK is 30% more emission-efficient in product i .

$$a_i^{UK} = \frac{(130 - 100)}{100} = 0.3 \quad (2\text{-}3)$$

Or, that there are 1.3 times as many emissions per unit of i produced in the RoW, compared to per unit of i produced in the UK.

$$e_i^{RoW} = 1.3 * e_i^{UK} \quad (2\text{-}4)$$

A penalty, in the form of an import tariff on goods coming from the RoW (t_i^{RoW}) can be set by assuming a base rate for the tariff (v) and scaling this according to the magnitude of the emission-efficiency adjustment. The larger the value of v the more extreme the price differential will be between imports and domestic-supply.

$$t_i^{RoW} = 1.3 * v \quad (2\text{-}5)$$

In the case that the UK has a higher emission-intensity, then it is relatively less emission-efficient in commodity i than the RoW. The adjustment a_i^{UK} takes a negative sign, accounting for the fact that fewer emissions are embedded per unit of commodity i imported from the RoW, than per unit of i produced within the UK. In this numerical example, a 30% difference in emission-efficiency is also applied, but with the UK relatively less emission-efficient in commodity i than the RoW.

$$a_i^{UK} = \frac{(140 - 200)}{200} = -0.3 \quad (2\text{-}6)$$

Or, that for every unit of emissions per unit of commodity i produced in the UK, there are only 0.7 units of emissions embedded in the same commodity imported from the RoW.

$$e_i^{RoW} = 0.7 * e_i^{UK} \quad (2\text{-}7)$$

In this case, the UK faces a tariff at the RoW border (t_i^{UK}) that depends on both the assigned base tariff rate (to determine the magnitude of the penalty) and a scaling factor based on the adjustment for relative emission-efficiency.

$$t_i^{UK} = 1.3 * v \quad (2\text{-}8)$$

2.2 UK and global emission impacts of GEBA

Within this framework, it is necessary to consider emissions from different perspectives to determine the impact of implementing a GEBA between the UK and the RoW[4]. Changes to the national 'source' and 'use' emissions help understand how, and to what degree, global GHG emissions from agriculture could be avoided.

[4] The FAPRI UK modelling system distinguishes between the European Union and Rest of World (other than the EU) in trade flows. However, for this analysis, both trade partners are combined into one block (Rest of World, or RoW).

Source emissions in the UK (E^{UK}_{source}) are defined in this framework as the emission-intensity per unit (e^{uk}_i) times the quantity of commodity supplied in the UK (q^{UK}_i). The source inventory represents the emissions associated with primary agriculture production within the territorial boundary, or production emissions.

$$E^{UK}_{source} = \sum_i e^{uk}_i \, q^{UK}_i \tag{2-9}$$

Use emissions represent the emissions associated with agriculture commodities consumed (as intermediate inputs or final demand) within the territorial boundary. Therefore, imports need to be added (to give us the total supply available) and exports taken away (to reflect what remains for use within the UK boundary). Use emissions here are defined as the source emissions (E^{UK}_{source}) plus emissions embedded in all imported commodities (with UK imports represented by m^{UK}_i), less emissions embedded in all the exported commodities (with UK exports represented by x^{UK}_i).

$$E^{UK}_{use} = E^{UK}_{source} + \sum_i (e^{RoW}_i \, m^{UK}_i - e^{UK}_i x^{UK}_i) \tag{2-10}$$

In the case the UK is more emission-efficient, and so a^{UK}_i is positive, and UK imports face a tariff, use emissions are expected to decrease (other things being equal). This is because a penalty at the border reduces the quantity of relatively more emission-intensive imports. Given UK production generates fewer emissions per unit of product, even if the *amount* produced in the UK increases to replace imports in the domestic market (along with source emissions), there will be a net reduction of use emissions[5]. Exports may decrease, as domestic commodities are now more competitive in the domestic market. This will also result in a reduction in use emissions, because if the quantity of the decrease in imports, matches the quantity of the decrease in exports, (assuming domestic consumption has not changed in volume terms) the average emission-intensity per unit consumed is now lower. This means, ultimately consumption emissions will decline.[6]

If the UK has a higher emission-intensity of production for a commodity, the border adjustment will discourage exports, and we can expect a reduction in production levels, imports, or a combination of both. Holding the level of imports constant, if domestic supply (production) decreases by the same quantity that exports decrease, then there is no impact on use emissions because the quantity used remains the same, and the emission-intensity per unit remains the same also [7]. If we hold domestic production constant, and exports decrease by the same amount imports decrease, then use emissions will increase. This is because of the difference between the emission-intensity of imported

[5] Let production in the UK increase by some amount b^{UK}_i so the use emissions related to product i will be $E^{UK}_{use,i} = E^{UK}_{source,i} + e^{UK}_i b^{UK}_i + e^{RoW}_i (m^{UK}_i - b^{UK}_i)$, and the change in use emissions will be $\Delta E^{UK}_{use,i} = (e^{UK}_i - e^{ROW}_i) b^{UK}_i$, so because $e^{UK}_i < e^{ROW}_i$, we know that $\Delta E^{UK}_{use,i} < 0$.

[6] Let imports of product i decrease by some amount, b^{UK}_i, and exports also decrease by the same amount to fill the gap in domestic demand, then the use emissions associated with that product will be $E^{UK}_{use,i} = E^{UK}_{source,i} + e^{RoW}_i (m^{UK}_i - b^{UK}_i) - e^{UK}_i (x^{UK}_i - b^{UK}_i)$, and the change in use emissions will be $\Delta E^{UK}_{use,i} = (e^{UK}_i - e^{RoW}_i) b^{UK}_i$, and because $e^{UK}_i < e^{RoW}_i$, we know that $\Delta E^{UK}_{use,i} < 0$.

[7] Let exports and production both reduce by the same amount, b^{UK}_i. Then the use emissions associated with that product will be $E^{UK}_{use,i} = E^{UK}_{source,i} - e^{UK}_i b^{UK}_i + e^{RoW}_i m^{UK}_i - e^{UK}_i (x^{UK}_i - b^{UK}_i)$ and the change in consumption emissions will be, $\Delta E^{UK}_{use,i} = (e^{UK}_i - e^{UK}_i) b^{UK}_i = 0$.

and exported goods, and that relatively lower emission-intensive imports are being replaced with higher emission-intensive domestic products[8].

It is important to consider that although source, and even use emissions, could increase for the UK if a GEBA is implemented, this does not mean *global* agricultural emissions increase. The relationship between implementing a border adjustment and emissions 'avoided' that otherwise would have added to the global volume also needs to be analysed.

The emissions avoided by implementing the adjustment can be inferred by estimating any shift in production from the jurisdiction with a higher emission-intensity to the more emission-efficient jurisdiction. If domestic use is defined as total supply (production plus imports) less exports, then production of commodity i in year t in the UK ($q_{i,t}^{UK}$) can be expressed as domestic use ($u_{i,t}^{UK}$) plus exports ($x_{i,t}^{UK}$) less imports ($m_{i,t}^{UK}$).

$$q_{i,t}^{UK} = u_{i,t}^{UK} - m_{i,t}^{UK} + x_{i,t}^{UK} \tag{2-11}$$

Therefore the change in UK production when the GEBA is implemented as a scenario (*s*) can be decomposed into three components, the change in domestic use, change in imports, and change in exports:

$$\left(q_{i,t,s}^{UK} - q_{i,t}^{UK}\right) = \left(u_{i,t,s}^{UK} - u_{i,t}^{UK}\right) - \left(m_{i,t,s}^{UK} - m_{i,t}^{UK}\right) + \left(x_{i,t,s}^{UK} - x_{i,t}^{UK}\right) \tag{2-12}$$

Or, using the symbol delta (Δ) to represent 'change in' this can be expressed as

$$\Delta q_{i,t}^{UK} = \Delta u_{i,t}^{UK} - \Delta m_{i,t}^{UK} + \Delta x_{i,t}^{UK} \tag{2-13}$$

Actual change in global production will depend on a multitude of interrelated variables, including relative and threshold values which are difficult to anticipate analytically. In this case, several simplifications are assumed so that an inferred impact of the GEBA on global emissions can be calculated. Specifically, it is assumed that the level of global production/consumption of commodity i in year t is the same when the GEBA is implemented, as in the baseline. It is also assumed that there is only one trade partner outside the UK. Therefore, any change in UK production under a GEBA scenario will result in the opposite impact on production in the RoW. In other words, if production increases in the UK, it decreases by the same amount in the Row. If UK production decreases, RoW production increases by the same amount.

$$\Delta q_{i,t}^{UK} = -\Delta q_{i,t}^{RoW} \tag{2-14}$$

The emissions 'avoided' by implementing the GEBA can be estimated as the difference in emissions per unit of product multiplied by the change in UK production.

$$E_{i,t}^{avoided} = a_i^{UK} e_i^{UK} \Delta q_{i,t}^{UK} \tag{2-15}$$

When $e_{i,s}^{ROW} > e_{i,s}^{UK}$, then a_i^{UK} is positive, so any increase in UK production levels results in global emissions being avoided. If the net impact is that production in the UK decreases, then the opposite would be the case, and there would be additional global emissions.

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[8] Let both exports and imports reduce by the same amount, b_i^{UK}. The use emissions associated with that product will be $E_{use,i}^{UK} = E_{source,i}^{UK} + e_i^{ROW}(m_i^{UK} - b_i^{UK}) - e_i^{UK}(x_i^{UK} - b_i^{UK})$, 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 $\Delta E_{use,i}^{UK} > 0$.

In the case that the UK has a higher emission-intensity, such that $e_{i,s}^{ROW} < e_{i,s}^{UK}$, then a_i^{UK} is negative, and a reduction in UK production results in global emissions being avoided, while an increase in UK production generates additional global emissions.

The overall impact, in terms of avoided emissions, can be compared across different cases by summing over products and years.

$$E_s^{avoided} = \sum_i \sum_t a_i^{UK} e_i^{UK} \Delta q_{i,t}^{UK} \tag{2-16}$$

2.3 Considerations

This simplified analytical framework illustrates important considerations for the UK. For instance, it allows us to incorporate, and then isolate, the impacts on UK competitiveness when emission-intensity is better or worse relative to trade partners. The consequences to the production base of UK agriculture are also captured, although this is an indirect, rather than direct impact of the GEBA. The UK's global economic competitiveness is corrected for 'carbon competitiveness' which changes the relative size of sub-sectors as they respond to relative price changes caused by the GEBA tariff itself, and the subsequent changes in the market due to altered trade flows. The primary purpose of the instrument is avoid carbon leakage, not to directly influence the size, structure or performance of UK agriculture, but if works to underpin and encourage actions taken to mitigate GHG emissions in production. Therefore, GEBA should not be considered as a replacement for national policies[9]. Instead it is *complementary*, by addressing some concerns around fairness and potentially perverse consequences resulting from some climate policies. The instrument is also *consistent* with broader efforts to decarbonise agriculture, because there is a systematic advantage to improve 'carbon competitiveness' to maintain, or gain, market share.

The next section describes how this stylised conceptual framework has been implemented within the FAPRI UK modelling system.

[9] The GEBA defined here is based on national averages, and therefore does not create an incentive at farm-level to reduce emission-intensity of production.

3 Implementation in the modelling system

The FAPRI-UK model is extended to illustrate projected UK source (production) and use (consumption) emissions, so that the impact of a simple hypothetical GEBA on UK and global emissions can be illustrated.

Published UK emissions inventory data in the most recent year available (2019) is linked to FAPRI-UK model variables. This allows baseline 'by source' emissions to be projected out to 2031 using calibrated emission factors, that can be compared to projected emissions when implementing GEBA scenarios. The relationship between emissions and model variables is also used to allocate emissions to dairy, beef, sheep, pig, poultry, wheat and barley activity, or, production. The emissions associated with each subsector are also allocated to commodity volumes to represent 'embedded' emissions, and determine the emission-intensity of UK agricultural traded commodities.

The emission-intensity per unit of agricultural output for the UK is used as a benchmark to assign a relative difference in emission-efficiency for agricultural output from the RoW. The assumed relative difference is used to calculate use, or consumption, emissions for the UK over the projection period, as well as an indication of the extent global of emissions avoided compared to the baseline. The price adjustment at the border is implemented as an *ad valorem* tariff on UK imports (RoW exports) when the emission-intensity per unit is higher than if that same commodity was produced domestically, and on UK exports (RoW imports) when there is a greater emission-intensity per unit of UK output of that commodity than if it was produced in the RoW.

The scenarios considered in this report are a considerable simplification. In reality, the UK will likely be *more* emission-efficient on average in some commodities, while being *less* emission-efficient on average in others. However, the objective here is to illustrate the mechanisms, and potential impacts of implementing a GEBA in a general sense. Therefore, the two extreme cases are presented (all UK commodities *more* or all UK commodities *less* emission-efficient), so that the impacts are clearly shown. Scenarios were run to check the effect of the GEBA on individual commodities in isolation, to validate scenario design and implementation. The results are not reported here, but are available as supplementary outputs.

The scenarios are delineated along two dimensions. The first considers whether the UK is *more* or *less* emission efficient in a commodity than the RoW. The second varies the scope to include a mix of commodities using three tiers or 'clusters'; cattle only-derived commodities, livestock-derived commodities, and finally, cereals and livestock-derived commodities (the full set of commodities considered in scope of GEBA).

The scenarios in no way reflect current or expected future relative emission-efficiencies, or attempt to 'predict' the exact pattern of production differences across trading partners and over time. Instead, they are designed to illustrate the potential boundaries around what could be observed in more extreme cases, and under a simple and stylised framing to help illustrate the main mechanisms driving the impacts.

3.1 Projecting GHG emissions by source

In the calibration stage of model development, The National Atmospheric Emission Inventory[10] and the FAPRI-UK deterministic baseline[11] are combined to provide a forward projection of agricultural production emissions. The FAPRI-UK deterministic baseline provides projections of price, production and trade flows from 2021 out to 2031. The most recent UK GHG Emission Inventory at the time of this analysis reports emissions for the year 2019. To align emissions with how agricultural activity is projected within the FAPRI-UK modelling framework, a calibration procedure is used to map emissions from the IPCC activity definitions, to the model variables. The relationship between the 2019 published inventory and the agricultural activity described within the modelling framework for the same year, is used to establish a deterministic baseline projection of source emissions from 2020 out to 2031. This process allows forecast emissions to be generated using FAPRI-UK units in the forms of population numbers (head count), area of crops (ha), or output volumes by weight (kg).

The published inventory volumes of methane (CH_4) and nitrous oxide (N_2O) emissions in 2019 are divided by model variables (animal numbers and crop areas) to generate a calibrated emission factor for each source category[12], and country within the UK (England, Wales, Scotland and Northern Ireland). The calibrated emission factors, EF_g^j ,for each country (*j*) and source category (*g*) are expressed in kilotonnes carbon dioxide equivalent[13] (kt CO_2 eq) per physical unit of model variable output, MV_g^j (head, unit weight, or hectare). The projected UK agriculture emission inventory for each year is calculated as:

$$E_{t,t\in projection}^{UK} = \sum_j \sum_g EF_g^j MV_{g,t}^j \qquad (3\text{-}1)$$

The projected emission inventory does not cover the full scope of the published inventory, as some agricultural sources are not included in the modelling framework. In the calibration year, 5240 kt CO_2 eq (11.3%) of agriculture source emissions were generated from goats, horses, deer, stationary and off-road energy use in agriculture-forestry-fishing, and lubricants. These are not included within the FAPRI-UK source emission projection.

3.2 Emission-intensity of UK agricultural commodities

The FAPRI-UK source emissions are used to assign an emission-intensity per unit of agricultural output. This is required to reflect the emissions 'embedded' within commodities actively traded

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[10] National Atmospheric Emission Inventory issued on 23/06/2021 ('Devolved Administration GHG Inventory 1990-2019) will be referred to as "Official UK GHG Emissions Inventory")

[11] Publications on the FAPRI UK deterministic baselines are available from https://www.afbini.gov.uk/fapri-publications.

[12] The source categories included in the calibration procedure include:
3A1 – 3A3 (enteric fermentation for dairy cows, other cattle, sheep and swine);
3B11 – 3B13, 3B21-3B23, and 3B25 (manure management for dairy cows, other cattle, sheep and swine);
part of 3B24 (to cover manure management emissions from poultry);
3D Agricultural soils (That include 3D11 Inorganic N Fertilizers, 3D12a Animal manure applied to soils, 3D12b Sewage sludge applied to soils, 3D12c Direct emissions from digestate etc…)
3G1 (to cover Liming – limestone); 3G2 (to cover Liming – dolomite); and 3H (Urea Application).

[13] The conversion from methane and nitrous are calculated in the inventory following GWP (Global Warming Potential) values for a 100-year time horizon (Fourth Assessment Report - 2007 (AR4)). Carbon dioxide CO_2 (1), Methane CH_4 (25), Nitrous oxide N_2O (298).

internationally. In these scenarios the GEBA is based on the UK average emission-intensity of each commodity, since trade policy is at UK level, instead of with the individual countries of the UK.

Source emissions (based on the calibration year 2019) are allocated to subsectors producing commodities with significant trade at the UK-level; dairy, beef, sheep, pig, poultry and cereals. In the case of some cattle emissions, there is not a direct correlation from national inventory source data aggregations to FAPRI-UK model subsectors, so assumptions were used to divide 'other cattle' emissions between dairy and beef.

Subsector emissions are divided by the volume of output to obtain the emission-intensity, e_i^{UK}. In the dairy subsector, there are five commodity outputs within the model (liquid milk, cheese, butter, skim milk powder, and whole milk powder). Therefore a secondary allocation process is applied based on the estimated percentage of raw milk utilised to manufacture each dairy commodity.

Table *3-1* shows the emission-intensity used for each commodity in the model. It also shows the assumed emission-intensities of commodities produced outside of the UK, assuming the RoW is either more or less emission-efficient by 30%.

Table 3-1 Emission-intensity of commodities produced in the UK and assumed for the RoW based on a 30% relative difference (kg CO2 eq per kg of commodity produced)

Commodity Name	Emission-intensity per unit (UK)	Emission-intensity RoW (30% less efficient)	Emission-intensity RoW (30% more efficient)
Cheese	7.14	9.28	5.00
Butter	1.60	2.07	1.12
Beef	11.82	15.37	8.28
Sheepmeat	13.71	17.82	9.59
Pigmeat	1.06	1.38	0.75
Poultry	0.17	0.22	0.12
Wheat	0.42	0.54	0.29
Barley	0.48	0.62	0.34

3.3 Framework to analyse the impacts on emissions

The GEBA scenarios test the impacts of adjusting for relative emission-efficiencies as part of international trade. As not all agricultural output is traded, and not all traded commodities are produced in the UK, the scope of emissions in the baseline used for comparison to the scenarios is defined to match the scope of the GEBA intervention. Commodities defined as in scope of the GEBA, with a notable share of UK agricultural trade, include cheese, butter, beef, sheepmeat, pigmeat, poultry, wheat and barley. To ease interpretation of the scenario results a UK source emissions inventory is projected that captures the GHG emissions associated with this sub-set of commodities.

The 'in scope' source emissions used for scenario analysis are defined as the unit emission-intensity (e_i^{UK}) multiplied by the volume of output (q_i^{UK}) for all 'GEBA commodities' and covers 71% of the baseline projected inventory[14].

$$E_{source}^{UK} = \sum\nolimits_{i,i \in GEBA} e_i^{UK} q_i^{UK} \tag{3-2}$$

[14] Commodities not included in the GEBA source inventory include liquid milk, skim milk powder, whole milk powder, oats and oilseed rape.

The emission-adjustment at the border is based on the relative difference in emission-efficiency, between the UK and its trading partner, here simplified to be the RoW[15]. However, the analytical framework can be generalised to accommodate multiple trading partners. The emission-intensity of RoW commodities is not estimated, instead an assumed relative difference is applied, for the purpose of these illustrative scenarios, with UK commodities as the reference point. Therefore, in practice, use, or consumption, emissions are calculated by replacing e_i^{ROW} with $\left(1 + a_i^{UK}\right)e_i^{UK}$. To ease analysis of the scenario results, as with the source emissions, commodities included in the inventory are limited to those identified as most significant to the GEBA adjustment (cheese, butter, beef, sheepmeat, pigmeat, poultry, wheat and barley).

$$E_{use,t}^{UK} = E_{source,t}^{UK} + \sum_i e_i^{UK}\left[\left(1 + a_i^{UK}\right) m_{i,t}^{UK} - x_{i,t}^{UK}\right] \quad (3\text{-}3)$$

The avoided emissions are already calculated without explicit reference to e_i^{ROW}.

3.4 Implementing the GEBA

The mechanism driving changes to trade, production, and thus emissions within the GEBA framework is an adjustment at the border that penalises imported commodities which have a greater emission footprint than that same commodity produced domestically. Taking the UK as the reference point, in the case where the UK imports beef that has a higher emissions content than beef produced domestically, the penalty will be applied to beef entering the UK. In the case where UK-produced beef has a relatively higher emission-footprint the penalty to UK exports of beef is applied as the beef enters the RoW market as an import. As the consequences for UK agriculture will differ depending on whether the emission-intensity of UK production for individual commodities is higher or lower than the RoW, both possibilities are included within the scenario analysis. In the analysis, this positive or negative penalty is applied across all commodities at the same level. This is to manage the number of scenarios as well facilitate an illustrative interpretation and presentation of scenario results.

The emission-adjustment at the border depends on the relative emission-efficiency. In reality, the emission differential could be much larger or smaller than 30%, and will vary from commodity to commodity. However, to illustrate the potential impact in a highly simplified but consistent manner, and do so in a non-trivial way, a uniform differential of 30% against the UK reference GHG intensity is imposed in all scenarios. That is, UK production is assumed to have a GHG unit intensity that is 30% more or 30% less than the RoW trading partner in all commodities. In both cases the metric is 30% of the estimated UK 2019 unit emission measured as kg CO_2 eq.

3.4.1 GEBA tariff

The GEBA penalty takes the form of an *ad valorem* tariff. For the illustrative purposes of this analysis the *ad valorem* tariff is set to 25% of the 5 year average of the UK price from 2016-2020. This rate is set in order to generate significant effects, while staying within reasonable bounds of the modelling system. The same price penalty is used for both cases (UK more and less emission-efficient) consistent with the assumption that the GHG intensity differential is the same for both cases (set to

[15] In the FAPRI UK modelling system there are two trade blocks, the European Union (EU) and the Rest of the World (RoW) other than the EU. Trade flows are modelled for each of these two blocks – however to reduce the number of scenarios required and simplify the analytical interpretation for this illustrative analysis, both trade blocks are subjected to the same GEBA tariff and emission adjustment at the border. Therefore, for the purposes of this report, the RoW refers to all countries outside of the UK, including the EU.

30%)[16]. In the case a commodity produced in the RoW generates 30% more emissions per unit than the same commodity produced in the UK, that commodity is subject to a tariff rate of 25% when imported to the UK. In the case producing a commodity in the UK generates 30% more emissions than to do so in the RoW, then UK exports of that commodity face the 25% tariff.

The expected impact of the GEBA tariff is to discourage replacing relatively emission-efficient domestically produced commodities with more emission-intensive imports, i.e 'carbon leakage'. The subsequent change in trade flows will largely drive change to the UK national use (consumption) emissions within the analysis. The analysis imposes higher and lower relative emissions on all traded commodities – regardless of existing competiveness. However, in a situation where one trade partner has a comparative advantage in emission-efficiency, this will improve competitiveness in international trade and encourage a pattern of specialisation globally that favours producing commodities with a carbon competitiveness advantage. This distributional impact will largely drive the resulting avoided emissions.

The impact on UK agriculture will depend on the context of each individual commodity (the direct effects), as well as how different subsectors interact with one another (the indirect effects).

Table 3-2 GEBA tariff for each commodity (£s per tonne)

Commodity	5 year average price (£ per tonne)	GEBA tariff – applied to imports from RoW (£ per tonne)
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

Some variation in the scope of GEBA, in terms of commodities that were subject to the emission and price differential, was included in the scenario analysis. The three degrees of scope, in terms of commodity clusters subject to the GEBA, are shown in Table *3-3*.

Table 3-3 Variation in scope of commodities included in the GEBA

Cereals and livestock-derived	Livestock-derived	Cattle-derived
Butter Cheese Beef Sheepmeat Pigmeat Poultry Wheat Barley	Butter Cheese Beef Sheepmeat Pigmeat Poultry	Butter Cheese Beef

[16] The assumption here is that the tariff rate is the same (25%) when the UK is both more, and less, emission-efficient. In this case we assume $t_i^{RoW} = t_i^{UK} = 0.25$, instead of scaling the base rate of *v*, which would be the approach if relative emission-efficiency was differentiated across commodities.

4. Baseline emissions and impacts under GEBA

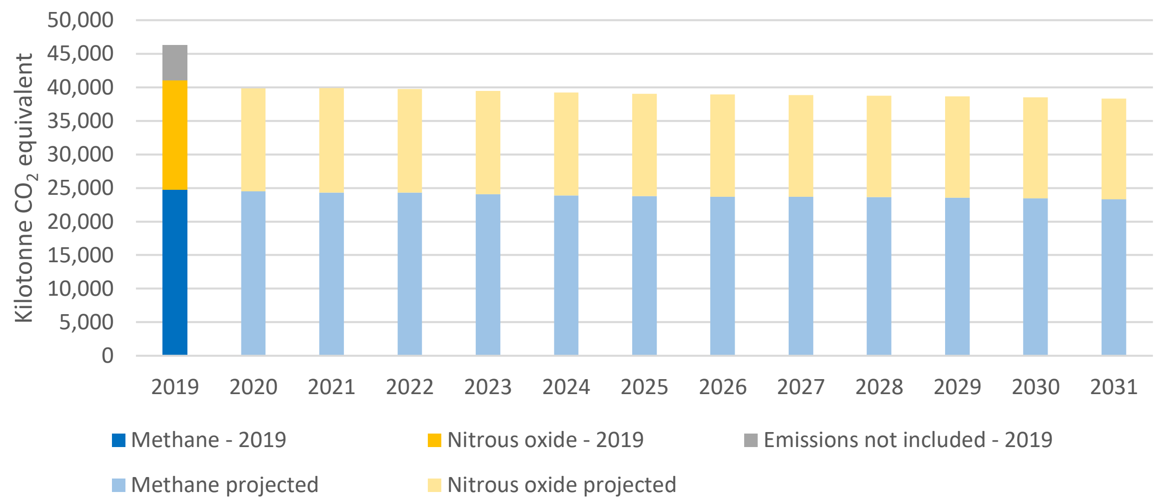
This section presents the UK agriculture source CH_4 and N_2O inventory as projected from the FAPRI-UK model out to the year 2031. The baseline emission projections developed specifically for the GEBA scenario analysis are also provided. These include, the UK source inventory projection for the commodities within scope of the GEBA analysis, as well as three baseline use emission projections. The first calculates use (consumption) emissions for UK agricultural commodities assuming there is no difference in emission-intensity between imports and domestically produced commodities. Two additional use emission baseline projections are required for use in the scenario analysis, because the use inventory directly depends on the (assumed) emission-intensity of the RoW, as well as the UK. Therefore, a use emission projection assuming the RoW is 30% more emission-intensive than the UK, as well as one assuming the RoW is 30% less emission-intensive, are also generated to use as a point of comparison against the relevant scenario. Illustrative results of the potential to prevent carbon leakage by implementing a GEBA are provided across scenarios and decomposed by commodity. The relative impacts on UK source and use emissions are also compared.

4.1 Greenhouse gas emission baseline projections

As outlined in Section *3 Implementation*, the National Atmospheric Emissions Inventory is used to project methane (CH_4) from enteric fermentation and manure management and nitrous oxide (N_2O) from manure management and related to agricultural soils out to the year 2031.

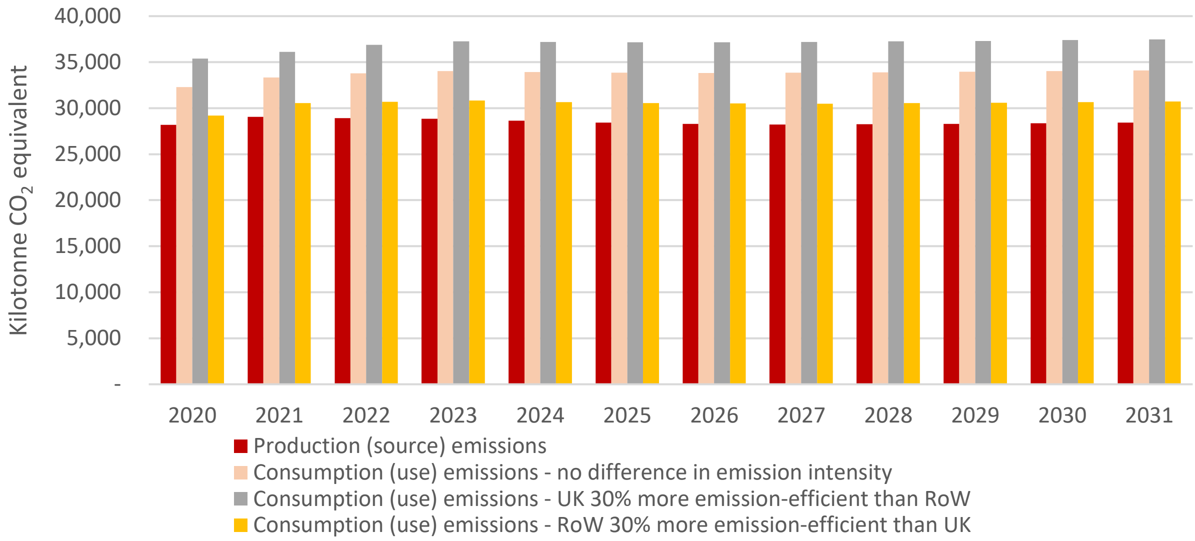
The projected source emission inventory, applying calibrated emission factors, shows a moderate decline with 2031 sitting 3.95% lower than 2021. The emission factors are held fixed over the period (in other words there is no change to the assumed emission-intensity of domestic agriculture during the period). The observed reduction reflects change in the activity data associated with emissions (livestock numbers and crop areas) and some minor productivity related impacts, as some technical progress is assumed within the projection period (e.g. upward trends in milk or crop yields) from underlying FAPRI-UK baseline assumptions.

Figure 4-1 Baseline CH4 and N2O agriculture source emissions



As described in Sections *2 Conceptual framework* and *3 Implementation*, a baseline of use emissions for agricultural goods consumed in the UK is also projected. This removes ‘exported’ emissions, adds ‘imported’ emissions, and assumes the same emission-intensity for UK and RoW produce. The projected production (source) and consumption (use) emissions associated with the products considered as part of the GEBA scenario analysis (cheese, butter, beef, sheepmeat, pigmeat, poultry, wheat and barley) are compared in Figure *4-2*. Due to the fact that the UK is largely a net importer of agricultural commodities, use emissions are greater than source emissions, and this persists over the projection period[17]. When it is assumed imported commodities have fewer embedded-emissions per unit, although the same volume is being imported, the gap between production and consumption emissions narrows (as a result of the better emission-efficiency of UK imports). Conversely, when the volume of net trade remains the same, but the emissions per unit imported is assumed to be greater (as a result of the worse emission- efficiency of UK imports), then then consumption emissions are higher.

Figure 4-2 Baseline production (source) and consumption (use) projected emissions comparing no difference and a 30% difference between emission-efficiency18



At the end of the projection period, when no difference between emission-intensity of commodities produced in the UK and the RoW is assumed, consumption emissions are 17% higher relative to production emissions. In the case where imported commodities have a lower emission-intensity, this difference is 8%, and when imported commodities have a higher emission-intensity, the difference increases to 24%.

4.2 Impacts of a GEBA on greenhouse gas emissions

Introducing the GEBA allows comparison between the pattern and volume of business-as-usual emissions, and the situation when the GEBA mechanism discourages the importation of commodities with a higher emission-intensity, but favouring the same domestically produced commodity.

Given the specific assumptions applied in this analysis, the subsequent contribution of a GEBA to reducing carbon leakage, and therefore potentially global emissions associated with agriculture, is illustrated by the impact on 'avoided' emissions. The link between avoiding global emissions, and increasing UK production (source) emissions when the UK can produce a commodity with more

[17] The proportional difference between consumption and production emissions is positive due to the fact that the UK is predominantly a net importer of the commodities considered here. However, there will not be a direct relationship to the proportional difference in volume, because each commodity has its own embedded-emissions factor.
[18] Only includes commodities in-scope of the GEBA

emission-efficiency than elsewhere is also illustrated. In the case of a commodity that can be produced with greater emission-efficiency outside the UK, consumption (use) emissions increase, because the loss of international competitiveness in trade means UK exports decline, and more domestic production is consumed domestically (replacing imports), and so the average emission-intensity of that commodity consumed in the UK increases.

It is important to keep in mind while reviewing these results that the GEBA mechanism does not directly induce changes in the structure of UK agriculture (rebalancing to produce a mix of lower intensity commodities), the way a sector-wide 'carbon tax' would by incentivising a shift in production towards relatively low-emission subsectors. Instead, each commodity is only compared to the same commodity produced outside of the UK, in order to determine its relative emission-intensity. This means that any structural changes arise, due to the shift in trade position caused by internalising *relative* emission-intensity within international trade (as opposed to internalising emission-intensity itself). Therefore, it is not surprising that the magnitude of change in UK emissions is relatively small.

4.2.1 Carbon leakage

Carbon leakage is when international trade facilitates the production of relatively low-cost, higher-emission commodities, to ultimately increase global emissions. In this analysis, to illustrate how addressing emission asymmetry at the border can directly resist carbon leakage an indicator of avoided global emissions is used. Global emissions are 'avoided' when *ceteris paribus* the share of global production is reallocated towards more emission-efficient producers.

Assuming global consumption remains constant, global agricultural emissions are reduced, following the imposition of the GEBA[19]. This is true whether the UK has more or less emission-intensive production than the RoW. Due to the UK being a net importer, there tends to be a larger impact when the GEBA operates a tariff on high emission imports, than when it is placed on high emission exports.

[19] This is a stylised case, whereby only the emissions generated during primary production are considered. The variation in transport method, distance, and associated emissions as part of international trade are not considered here.

Figure 4-3 Total global greenhouse gas emissions avoided under GEBA (2022-2031) when the UK is more emission-efficient and an import tariff is applied

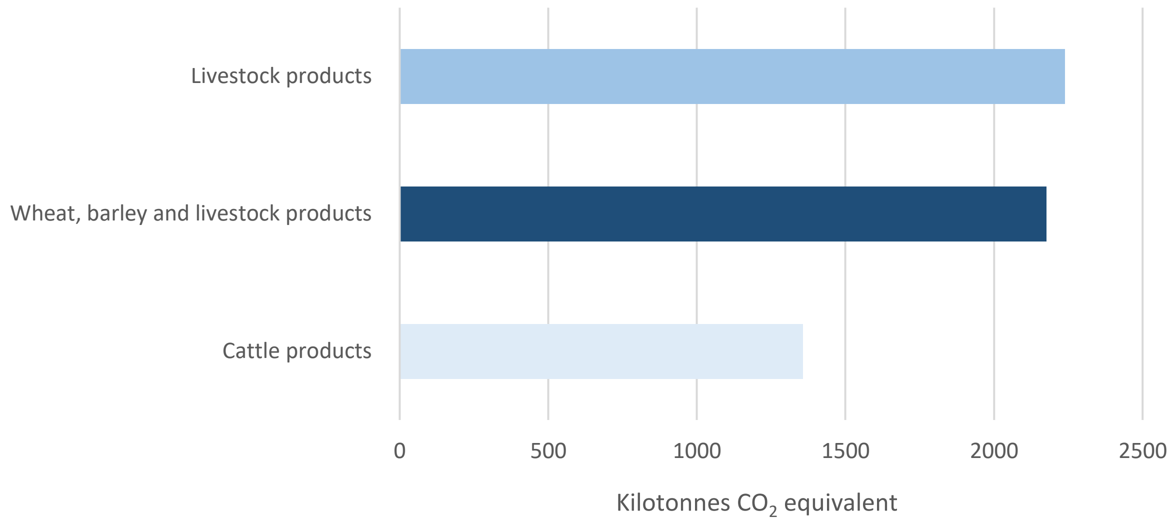
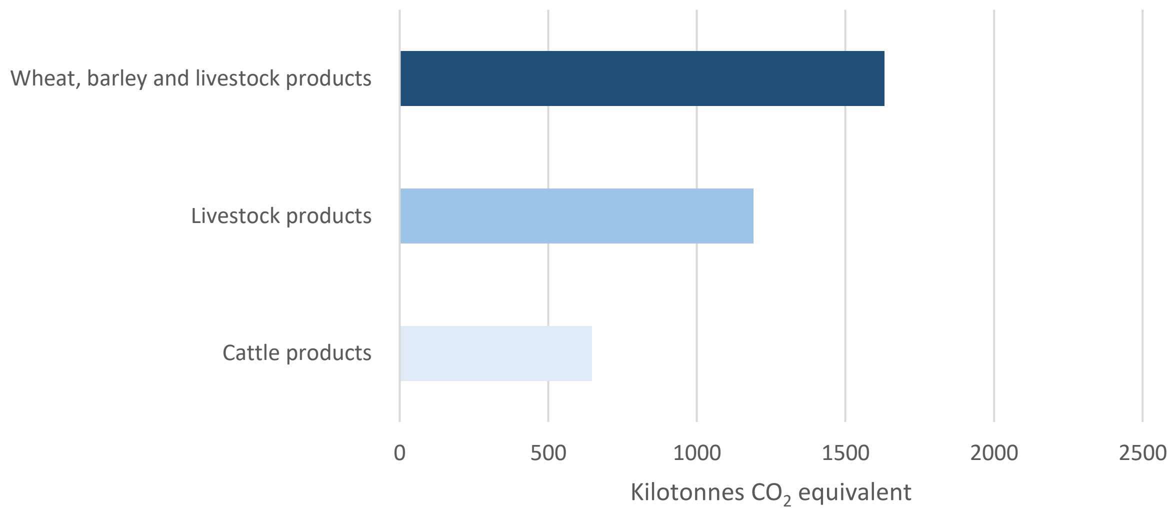


Figure 4-4 Total global greenhouse gas emissions avoided under GEBA (2022-2031) when the UK is less emission-efficient and an export tariff is applied



Depending on the emission-intensity of a commodity, and the pattern of trade flows, each commodity will make a different relative contribution to avoiding carbon leakage. The greater the production change in the UK, and emission-intensity of a commodity, the larger the impact on avoided emissions. Therefore, the avoided emissions are also decomposed by commodity in Figure *4-5* and Figure *4-6*. When the UK is more emission-efficient than the RoW, the redistribution of beef and cheese production to the UK makes the largest contribution. When the UK is less emission-efficient than the Row, the transfer of sheepmeat production out of the UK has a relatively large impact on avoided global emissions compared to other commodities.

Figure 4-5 Avoided global emissions by product (2022-2031) when the UK is more emission-efficient and an import tariff is applied

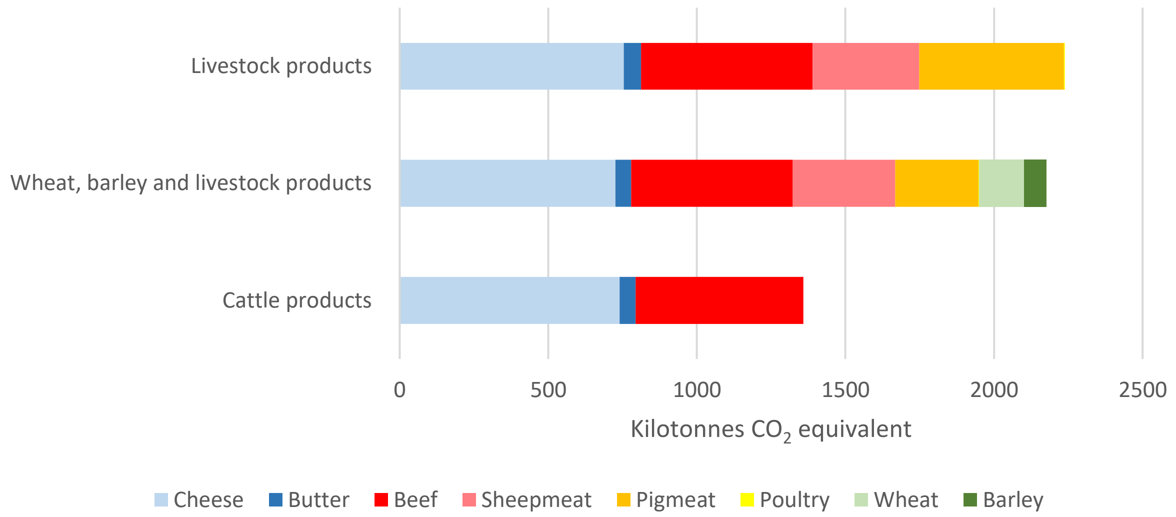
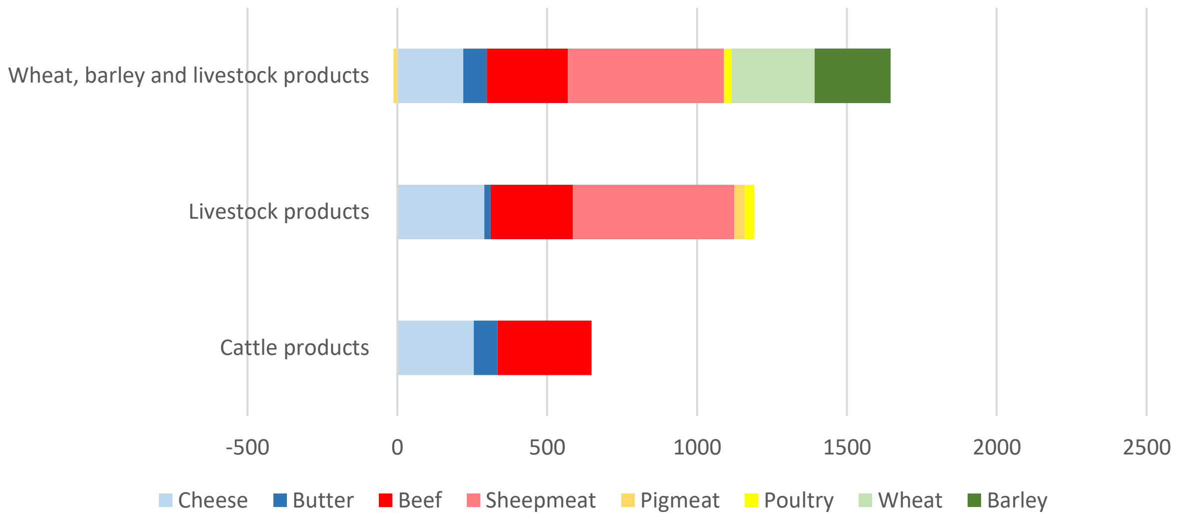


Figure 4-6 Avoided global emissions by product (2022-2031) when the UK is less emission-efficient and an export tariff is applied

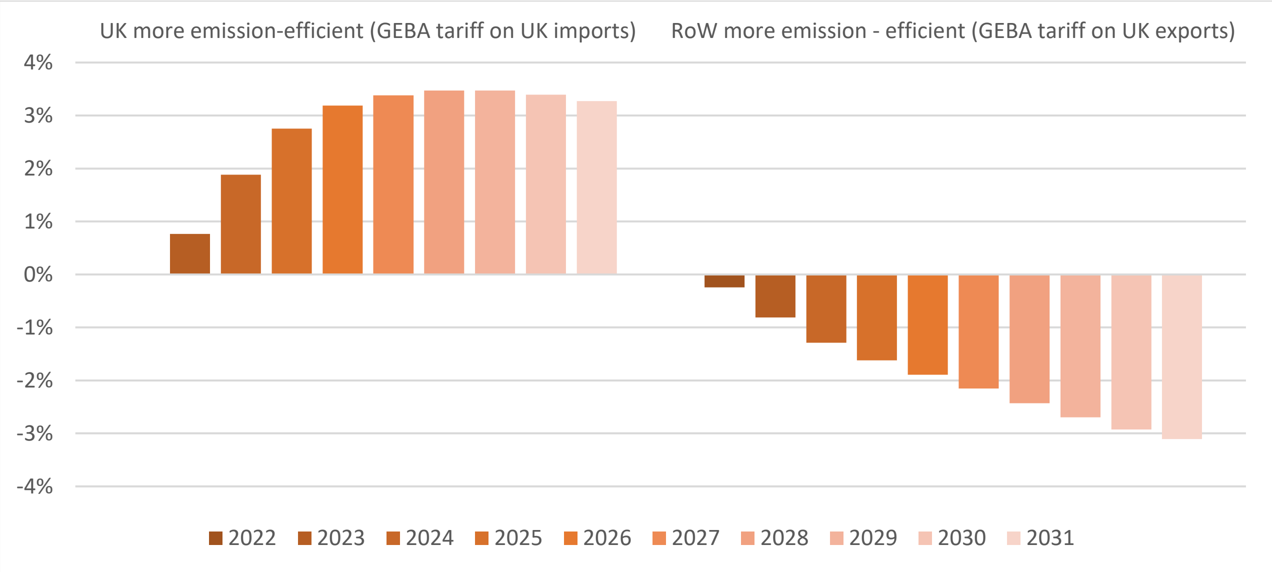


4.2.2 Production (source) emissions

Production, or source, emissions are sensitive to changes in the emission-intensity per unit of production, and, the amount that is produced, within a territorial boundary. In this analysis, the assumption is that there is no direct link between implementing the GEBA and the emission-intensity per unit of a commodity[20]. Therefore, changes to agricultural source emissions are driven by production volume changes.

Implementing the GEBA when the UK has higher emission-efficiency, resulting in a tariff on UK imports, encourages additional domestic production compared to the baseline, as imports are now relatively more expensive. This in turn increases production emissions. In the situation when the UK has a relatively lower emission-efficiency, and therefore a disadvantage in trade due to the GEBA tariff being applied to UK exports, there is downward pressure on domestic production levels. Figure *4-7* charts the percent difference between production emissions in each case and the baseline estimates.

Figure 4-7 Percent difference from baseline source emissions when UK is 30% more, or less, emission-efficient than the RoW



4.2.3 Consumption (use) emissions

Consumption, or use, emissions depend on the volume of a commodity used domestically, and the average emission-intensity of that commodity weighted by origin (domestic or imported). Therefore, the emission inventory for the UK by use will be sensitive to both changes in volume (consuming more or less of a commodity) as well as the share of imports (if imports have a different level of embedded emissions). The GEBA can impact both elements. Price changes triggered by the tariff, increasing UK import prices, or conversely reducing domestic prices due to a tariff on UK exports, can alter how much of that commodity is consumed due to own and cross price elasticity effects. The price differential caused by the GEBA will also trigger substitution in terms of how much of UK demand is filled from imported and domestically produced supply. As all the commodities assumed in scope of the GEBA in this analysis are also produced domestically, the substitution between imported and domestically produced commodities is the main driver.

[20] The GEBA is assumed to have no impact on emission-intensity during the projection period.

When the GEBA tariff is applied to UK imports, because they are more emission-intensive, UK consumption (use) emissions are 2-3% below the baseline projected level. The disincentive at the border for relatively emission-intensive imports has successfully lowered the emission requirement to meet domestic demands. However, the GEBA has the opposite outcome on consumption emissions when the tariff is applied to UK exports, with the use inventory about 3% above the baseline. In this case, the disincentive to export due to the tariff has improved the relative price position of domestic commodities, increasing their share of domestic use, and so also emissions per unit consumed. Figure *4-8* charts the percent difference in use emissions between the baseline and GEBA scenarios.

Figure 4-8 Percent difference from baseline use emissions when UK is 30% more, or less, emission-efficient than the RoW

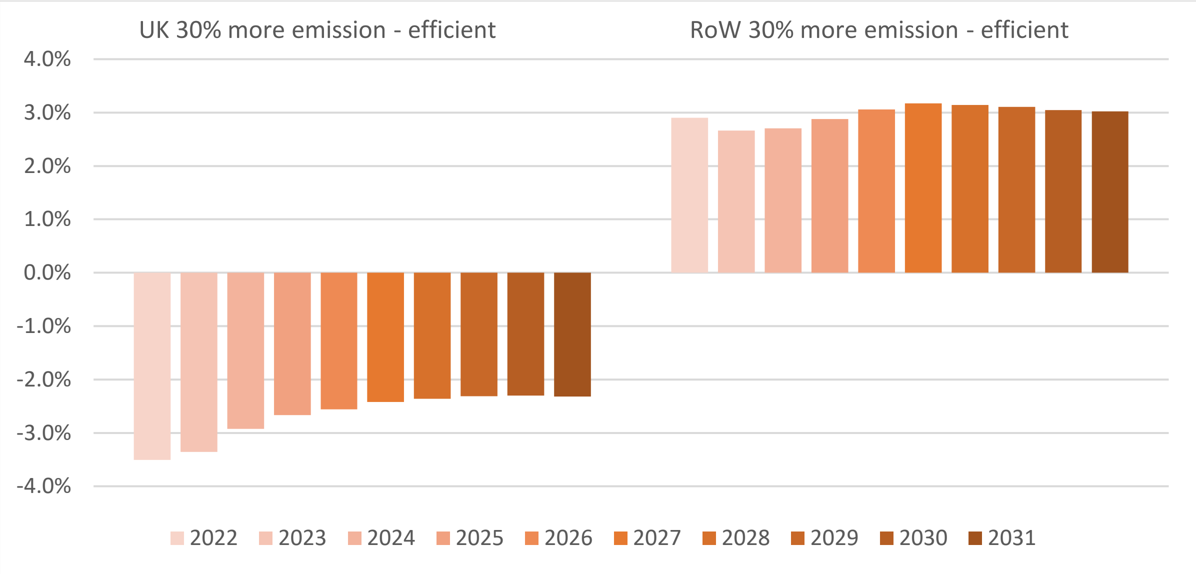


Table 4-1 decomposes the change in consumption emissions associated with each commodity into three components: the change to source, imported, and exported emissions. Production plus imported less exported emissions calculates the net change to consumption (use) emissions.   The net reduction in use emissions when the GEBA tariff falls on UK imports is largely driven by a reduction in i-mported emissions embedded in beef and cheese. The net increase in consumption (use) emissions when the GEBA penalises UK exports is mainly caused by a failure to export emissions embedded in beef, and to a lesser extent cheese and sheepmeat.

Table 4-1 Total difference between GEBA and baseline consumption (use) emissions decomposed into production, import, and export emissions over the period 2022-2031 (killotonnes CO2 equivalent)

Commodity	Baseline total production	Emissions change (GEBA – baseline)							
		GEBA tariff on UK imports				GEBA tariff on UK exports			
		Production	*Imported*	*Exported*	*Use*	*Production*	*Imported*	*Exported*	*Use*
Cheese	34,397	2,419	-8,880	-2,937	-3,523	-733	-1,837	-4,029	1,459
Butter	3,022	178	-786	-386	-222	-262	-241	-786	283
Beef	101,467	1,812	-12,057	-4,825	-5,421	-900	-2,455	-8,198	4,843
Sheepmeat	38,568	1,150	-3,347	-1,056	-1,141	-1,738	-1,469	-4,608	1,401
Pigmeat	9,052	934	-930	760	-756	42	-702	-1,097	436
Poultry	3,554	6	-57	38	-88	-85	-62	-157	10
Wheat	59,525	506	-270	-316	551	-923	-126	-1,342	292
Barley	35,060	248	-166	-508	590	-840	-159	-1,300	301

5 Economic impacts

The GEBA functions *via* a price instrument to incorporate relative emission-efficiency within the scope of competitiveness in international trade. Therefore, the economic impacts are driven by the changes in relative prices, emanating from the *ad valorem* tariff imposed on imported commodities that have a higher level of embedded emissions than the same commodity produced domestically.

In line with expectations, when the GEBA tariff is imposed on imports to the UK of a livestock-derived commodity, the price for that commodity increases along with UK production, and domestic use declines compared to the baseline. UK domestic use increases in the case of cereals, even when they are subject to a GEBA import tariff, when this is the driven by higher UK production of livestock derived commodities because of the over-riding effect of increased demand for animal feeds.

The impact of a GEBA tariff on UK commodity exports entering foreign markets is to decrease UK prices and overall production while increasing domestic use. This is true for both livestock-derived and cereal commodities when they are subject to the GEBA tariff. When some or all UK livestock commodities are subject to the tariff, but cereals are not, domestic use for cereals decreases, because of the over-riding effect of decreased demand for animal feeds..

Any commodity subject to a GEBA tariff, regardless of whether it falls on UK imports or exports, decreases the share of imports in domestic use. The magnitude of this impact is stronger in the case of UK imports, than when the tariff applies to UK exports.

5.1 Price, production and domestic use results by commodity

Details of the price, production and domestic use differences under GEBA scenarios compared to the baseline are provided. While all livestock commodities, and both cereal commodities, follow the same general pattern respectively, there is variation in relative magnitudes. The scenario design implements a uniform 25% tariff rate on all commodities subject to the GEBA. The advantage here is that the variation in price impacts across commodities is not related to a varied tariff rate (for instance if the tariff had been directly tied to emission-intensity itself instead of an assumed relative difference between the UK and RoW). This aids in interpreting the price impact of the tariff reported here as related to the unique context of the corresponding subsector in the UK.

The 25% GEBA tariff on UK imports results in an average 16% price increase for cheese over the projection period, and a much smaller negative price impact of about -6% when the tariff inhibits UK exports (Table *5-1*). Butter price follows the opposite pattern, with a lower price increase (of about 4%) when UK imports face a tariff, and a much greater decrease of -16% when it is UK exports subject to the GEBA (Table 5-2). Production increases as a result of tariffs on UK imports are similar (between 6-8%) but decreases when tariffs are applied to UK exports are more varied with cheese at only -3% different from the baseline and butter -9%. The significant decrease in butter price and production are a result of a reduction in trade as exports are no longer viable. The farmgate price of milk averages out to a 17% difference from the baseline in the case of GEBA tariffs on UK imports, and -8% difference in the GEBA export tariff scenario Dairy cow number increases 3%, and when production declines the difference from the baseline is as much as -1.5%.

When beef is subject to the 25% tariff, price moves about 5.5% above the baseline when imposed on UK imports, and below the baseline, with a difference of -11%, when imposed on UK exports (Table *5-3*). When price increases, this stimulates additional production, averaging out to about 3%, backed by an additional 4% of suckler cows. When price sits below the baseline level, this leads to a -1.5% difference to production levels, resulting in suckler cows averaging -4.5% compared to the baseline.

When only cattle-derived products are subject to the GEBA, there are very small deviations from the baseline projected levels of ewes, prices, production and domestic use, less than + / – 1% (Table *5-4*). In the case sheepmeat is subject to the GEBA, the magnitude of price changes is much larger in the case of downward pressure due to UK exports being subjected to the tariff (-13% difference) compared to upward pressure from the tariff on imports (4% difference). It follows, the more extreme price difference also sees the more extreme differences in production, domestic use, and ewe numbers.

Both pigmeat and poultrymeat experience minimal deviation from the baseline when only cattle-derived commodities are included within the scope of the GEBA (Table *5-5* and Table *5-6*). When dairy, beef, pigmeat and poultry, but not cereals, are in scope of the GEBA there are significant departures from the baseline in the case of pigmeat. The 25% tariff on imports to the UK almost entirely transmits to pigmeat price, with an average +21% difference from the baseline. This translates into large production increases (+22% difference) and therefore sow number (+21%). This is due to the relative size of imports in UK consumption. Domestic use responds with a -6% difference compared to the baseline. In this scenario, cereal prices remain high and therefore feed input costs are also high for the pig sector. As a result, there is a significant decline experienced in both imports and exports.

Poultry price is more sensitive to the tariff when it applies to UK exports, than UK imports, with price between -7% and -8% from the baseline. The lower prices reduce production by between -2% and -3% from the baseline level, and increases domestic use by about 1.3% from the baseline.

The impact to cereals is minimal when only cattle-derived products are subject to the GEBA, with more visible differences from the baseline once pigmeat and poultry are in scope - due to its use as a key input (Table *5-7* and Table *5-8*). When UK imports face the tariff, wheat and barley prices are between 4% and 5% above the baseline. Wheat price averages -7.6% from the baseline, and barley -13% when cereals as well as livestock-derived commodities produced in the UK face the tariff on exports.

Table 5-1 Percent difference between the baseline and each scenario for cheese

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Total Dairy Cows	1.25	2.63	3.13	3.15	-1.00	-1.39	-1.34	-1.51
Price	12.22	16.79	16.21	15.98	-8.83	-4.62	-5.31	-6.33
Production	2.99	6.52	7.90	7.76	-1.44	-2.42	-2.37	-2.63
Domestic Use	-1.93	-2.51	-2.43	-2.40	1.58	0.78	0.90	1.08
Farmgate price (En)	8.18	14.14	16.07	17.01	-6.43	-6.25	-6.67	-7.95
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Total Dairy Cows	1.29	2.73	3.25	3.20	-0.89	-1.19	-1.10	-1.19
Price	12.64	17.64	17.04	16.54	-8.82	-4.83	-5.50	-6.27
Production	3.09	6.71	8.15	7.88	-2.11	-2.81	-2.73	-2.93
Domestic Use	-1.99	-2.62	-2.54	-2.48	1.57	0.82	0.93	1.07
Farmgate price (En)	8.47	14.84	16.93	17.65	-5.83	-5.40	-5.70	-6.55
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Total Dairy Cows	1.23	2.58	3.07	3.08	-0.91	-1.23	-1.17	-1.35
Price	12.22	16.80	16.20	15.96	-8.84	-4.65	-5.34	-6.31
Production	2.94	6.41	7.77	7.60	-1.25	-2.06	-1.99	-2.28
Domestic Use	-1.93	-2.51	-2.43	-2.40	1.58	0.78	0.90	1.08
Farmgate price (En)	8.19	14.15	16.07	16.99	-6.44	-6.28	-6.70	-7.94

Table 5-2 Percent difference between the baseline and each scenario for butter

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Price	5.07	3.52	3.42	4.10	-15.54	-14.73	-14.85	-15.98
Production	4.79	5.57	5.87	6.18	-8.87	-8.42	-8.38	-8.93
Domestic Use	-1.43	-1.00	-0.98	-1.16	5.03	4.74	4.79	5.20
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Price	5.33	4.52	4.42	4.53	-1.83	-1.76	-1.56	-1.12
Production	5.00	6.28	6.58	6.50	-2.52	-2.35	-2.21	-2.15
Domestic Use	-1.50	-1.28	-1.25	-1.28	0.54	0.52	0.46	0.33
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Price	5.07	3.53	3.42	4.10	-15.56	-14.77	-14.89	-16.01
Production	4.76	5.53	5.80	6.11	-8.80	-8.29	-8.23	-8.79
Domestic Use	-1.43	-1.00	-0.98	-1.17	5.04	4.76	4.80	5.21

Table 5-3 Percent difference between the baseline and each scenario for beef

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Total Suckler Cows	0.99	2.73	4.24	3.93	-0.34	-1.04	-1.89	-4.88
Price	15.31	13.98	11.63	5.41	-5.24	-6.05	-7.37	-11.30
Production	-0.93	-1.19	-0.24	3.03	0.58	0.39	-0.03	-1.63
Domestic Use	-3.41	-3.13	-2.64	-1.27	1.33	1.54	1.89	2.96
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Total Suckler Cows	1.01	2.77	4.31	4.05	-0.29	-0.93	-1.70	-4.62
Price	15.58	14.18	11.93	5.76	-4.75	-5.63	-6.97	-10.97
Production	-0.96	-1.22	-0.24	3.1	0.52	0.32	-0.03	-1.43
Domestic Use	-4.07	-3.77	-3.10	-1.72	1.68	1.86	2.25	3.45
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Total Suckler Cows	0.95	2.61	4.06	3.70	-0.28	-0.86	-1.56	-4.35
Price	14.94	13.60	11.36	5.26	-4.74	-5.62	-6.94	-10.98
Production	-0.91	-1.15	-0.22	2.92	0.52	0.31	-0.05	-1.40
Domestic Use	-3.85	-3.56	-2.89	-1.51	1.68	1.86	2.25	3.47

Table 5-4 Percent difference between the baseline and each scenario for sheepmeat

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Total Ewes	-0.05	-0.08	-0.11	-0.08	0.02	0.04	0.06	0.10
Price	-0.24	-0.21	-0.15	-0.04	0.09	0.10	0.11	0.14
Production	0.03	0.00	-0.05	-0.10	-0.01	0.00	0.02	0.09
Domestic Use	-0.69	-0.63	-0.53	-0.25	0.26	0.30	0.37	0.56
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Total Ewes	2.29	4.08	4.66	3.19	-1.73	-3.17	-4.57	-7.46
Price	12.45	11.84	5.12	4.09	-9.24	-8.37	-9.90	-13.03
Production	-1.41	0.12	3.13	4.23	1.02	-0.03	-1.62	-6.67
Domestic Use	-2.26	-2.11	-1.12	-0.67	1.48	1.41	1.73	2.40
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Total Ewes	2.24	4.00	4.56	2.97	-1.67	-3.04	-4.39	-7.27
Price	12.17	11.71	5.01	3.69	-9.23	-8.36	-9.91	-13.11
Production	-1.37	0.11	3.07	4.06	0.98	-0.05	-1.56	-6.46
Domestic Use	-2.24	-2.12	-1.13	-0.65	1.47	1.40	1.72	2.40

Table 5-5 Percent difference between the baseline and each scenario for pigmeat

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Total Sows	-0.16	-0.21	-0.23	-0.30	0.06	0.12	0.16	0.27
Price	-0.29	-0.15	-0.06	-0.03	0.10	0.10	0.11	0.15
Production	-0.03	-0.13	-0.21	-0.30	0.01	0.06	0.12	0.26
Domestic Use	-0.44	-0.44	-0.38	-0.18	0.17	0.20	0.25	0.40
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Total Sows	10.64	16.54	19.12	21.32	-1.11	-1.46	-1.52	-1.39
Price	21.05	21.97	21.37	21.71	-2.27	-1.91	-1.78	-1.62
Production	2.21	9.63	16.41	21.88	-0.21	-0.94	-1.45	-1.47
Domestic Use	-5.78	-5.96	-5.87	-5.78	0.47	0.45	0.44	0.50
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Total Sows	6.42	9.82	10.96	12.25	-0.67	-0.18	0.33	0.85
Price	12.80	13.34	12.27	12.85	-1.73	-1.36	-1.11	-0.97
Production	1.33	5.77	9.67	12.54	-0.12	-0.41	-0.20	0.79
Domestic Use	-3.76	-3.87	-3.65	-3.62	0.47	0.45	0.46	0.53

Table 5-6 Percent difference between the baseline and each scenario for poultrymeat

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Price	-0.09	-0.03	0.02	0.07	0.02	0.02	0.02	0.03
Production	-0.03	-0.06	-0.10	-0.15	0.01	0.04	0.06	0.10
Domestic Use	-0.04	-0.05	-0.05	-0.03	0.02	0.02	0.03	0.05
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Price	1.93	1.61	1.70	1.71	-9.95	-8.44	-7.79	-6.96
Production	0.44	0.50	0.45	0.21	-2.30	-3.05	-3.22	-2.95
Domestic Use	-0.35	-0.30	-0.31	-0.30	1.69	1.44	1.34	1.23
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Price	1.59	1.51	1.59	1.57	-9.99	-8.89	-8.37	-7.71
Production	0.32	0.31	0.27	0.12	-2.20	-2.62	-2.63	-2.37
Domestic Use	-0.29	-0.28	-0.29	-0.27	1.70	1.52	1.44	1.37

Table 5-7 Percent difference between the baseline and each scenario for wheat

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Crop Area	0.04	0.12	0.18	0.26	-0.03	-0.07	-0.10	-0.12
Price	0.39	0.94	1.03	1.56	-0.32	-0.53	-0.50	-0.76
Production	0.05	0.14	0.21	0.31	-0.04	-0.09	-0.11	-0.15
Domestic Use	0.19	0.37	0.50	0.57	-0.16	-0.19	-0.20	-0.26
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Crop Area	0.08	0.29	0.53	0.78	-0.08	-0.19	-0.28	-0.33
Price	0.76	2.39	3.41	4.63	-0.77	-1.43	-1.54	-1.92
Production	0.09	0.34	0.62	0.94	-0.09	-0.23	-0.33	-0.39
Domestic Use	0.38	1.08	1.70	2.08	-0.38	-0.51	-0.60	-0.65
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Crop Area	0.25	0.48	0.70	0.81	-0.68	-1.26	-1.57	-1.39
Price	2.55	3.23	3.89	4.73	-6.25	-7.55	-7.15	-7.60
Production	0.30	0.57	0.83	0.97	-0.78	-1.45	-1.82	-1.64
Domestic Use	-0.11	0.52	0.94	1.21	0.42	0.37	0.26	0.37

Table 5-8 Percent difference between the baseline and each scenario for barley

Year	2022	2023	2024	2025-2031 average	2022	2023	2024	2025-2031 average
	GEBA – imported cattle commodities				**GEBA – exported cattle commodities**			
Crop Area	0.03	0.10	0.15	0.20	-0.03	-0.06	-0.08	-0.09
Price	0.32	0.74	0.95	1.23	-0.27	-0.41	-0.41	-0.57
Production	0.04	0.11	0.18	0.25	-0.03	-0.07	-0.09	-0.11
Domestic Use	0.34	0.70	0.84	1.04	-0.28	-0.37	-0.37	-0.49
	GEBA – imported livestock commodities				**GEBA – exported livestock commodities**			
Crop Area	0.07	0.25	0.47	0.69	-0.07	-0.16	-0.22	-0.24
Price	0.65	2.07	3.26	4.29	-0.64	-1.09	-1.24	-1.42
Production	0.08	0.29	0.55	0.84	-0.08	-0.18	-0.26	-0.29
Domestic Use	0.70	2.04	2.99	3.64	-0.70	-1.04	-1.15	-1.29
	GEBA – imported cereals and livestock commodities				**GEBA – exported cereals and livestock commodities**			
Crop Area	0.18	0.38	0.56	0.68	-0.97	-1.74	-2.23	-2.10
Price	1.53	2.60	3.34	4.12	-10.54	-12.79	-12.75	-13.29
Production	0.20	0.44	0.66	0.82	-1.16	-2.09	-2.68	-2.57
Domestic Use	0.66	1.48	2.12	2.52	0.74	0.76	0.74	0.61

Table *5-9* shows the percentage of UK domestic use that is met by imports for each of the commodities in the baseline. It also shows the percentage change (with reference to the baseline) in each of the GEBA scenarios. In the baseline, only a small percentage of domestic use is made up of imports for cereal products, whereas there is a much larger proportion of domestic use comprised of imports for livestock products, ranging from 20%-65%. When a GEBA is applied to either imports to the UK or exports from the UK, each commodity experiences a decrease in the proportion of domestic use contributed by imports.

Table 5-9 Baseline proportion of UK domestic use filled by imports compared with each GEBA scenario

	Baseline % of domestic use imported	**% Change from the baseline**	
	Average (2022-2031)	**GEBA - imported cattle commodities**	**GEBA - exported cattle commodities**
Cheese	64.91	-14.99	-7.24
Butter	36.41	-46.75	-30.17
Beef	33.86	-19.98	-11.45
Sheepmeat	30.57	-0.40	0.63
Pigmeat	49.65	0.06	0.10
Poultry	21.34	0.26	-0.18
Wheat	9.72	0.40	-0.08
Barley	0.97	4.18	-2.05
		GEBA - imported livestock commodities	**GEBA - exported livestock commodities**
Cheese	64.91	-15.00	-7.82
Butter	36.41	-46.88	-3.86
Beef	33.86	-21.03	-11.26
Sheepmeat	30.57	-22.42	-19.80
Pigmeat	49.65	-38.37	-11.65
Poultry	21.34	-5.61	-10.37
Wheat	9.72	2.54	1.03
Barley	0.97	13.99	-2.28
		GEBA - imported cereals and livestock commodities	**GEBA - exported cereals and livestock commodities**
Cheese	64.91	-14.88	-7.49
Butter	36.41	-46.68	-30.44
Beef	33.86	-20.07	-10.93
Sheepmeat	30.57	-22.51	-20.63
Pigmeat	49.65	-6.35	-14.12
Poultry	21.34	-5.21	-12.35
Wheat	9.72	-4.32	-3.29
Barley	0.97	-46.22	-80.37

6. Conclusion

Given the transboundary nature of both GHGs and the food system, achieving both climate objectives and food security, will depend largely on how international trade in agricultural commodities is managed. In this context, to align the global food system with national efforts to reduce harmful emissions, requires the social cost of emissions embedded within agricultural commodities. Internalising some or all of the cost of emissions within trade can reduce the potential for ambitious national emission standards to result in unintended relocation of production (carbon leakage) in a way that works against the objective of reducing the global volume of emissions. Moreover, incorporating emission-efficiency as a component in international competitiveness can encourage a re-allocation of production to places with a carbon advantage, which can contribute to reducing the average emission-intensity of global agriculture, and so help meet global emission reduction targets. This analysis explores the potential impacts of implementing an adjustment at the border on agricultural commodities to favour lower emission commodities in a bi-lateral trading relationship – i.e. both partners are suppliers of the commodity in question but have unequal emission-intensity of production.

The framework established takes into account the complex challenges associated with agriculture, and concerns around maintaining a sufficient supply of food for the global population. Therefore, the adjustment at the border deals specifically with the relative emission-intensity of the same commodity produced domestically in the UK, or in a third country. This results in an *ad valorem* tariff for imports to the UK when the UK has the carbon advantage, and a tariff on UK exports when the trading partner has the carbon advantage.

The emission-intensities of UK agricultural commodities are used as a reference point to project source (production) and use (consumption) emissions, and establish the impact on UK emissions when the GEBA is introduced. The analysis undertaken illustrates the impact the GEBA could have on UK output, imports, exports and prices, when UK emission-intensity is higher or lower than that of the RoW.

6.1 Findings

In the case the GEBA tariff is imposed on imports to the UK (because the UK has lower emissions per unit of commodity produced) it protects domestic producers compared to the baseline, imports and exports decrease, and domestic production increases marginally (along with prices). The increase in domestic production leads to more UK production (source) emissions than without the GEBA intervention. Consumption (use) emissions, however, are lower in the case of a GEBA than they would be otherwise, because relatively more emission-intensive imports are displaced by their relatively less emission-intensive domestic counterparts. In other words, the UK is importing fewer emissions. Assuming there is no difference in global consumption/production of agricultural commodities, the global volume of methane and nitrous oxide is lower when a GEBA is imposed. This is because the increase in UK production displaces more emission-intensive production that would have occurred outside the UK. However, as UK emissions (as measured by the source inventory method) increase, progress to reduce aggregate national emissions is hindered unless a border adjustment on high emissions imports is accompanied by policies that reduce the emissions intensity of UK production.

In the case the GEBA tariff is imposed on UK exports (because the UK has higher emissions per unit of commodity produced) it results in an overall decrease in domestic agricultural production compared to the baseline because exports are less price competitive and export volumes decline.

However, domestic production takes a larger share of domestic consumption (at a lower price), and imports decrease (compared to the baseline). In this scenario, as overall UK production decreases, total UK emissions (as measured by the source inventory method) decrease, and progress to reduce aggregate national emissions is helped. In contrast, UK consumption (use) emissions increase, because fewer emissions are being 'exported' from the UK, leading to the average emission-intensity of the commodity consumed domestically being higher under a GEBA compared to the baseline. This is because of the larger share of relatively emission-intensive commodity that is sourced domestically.

The scope of the agricultural commodities subject to a GEBA is also varied across scenarios. In line with results described in Finding One, when the GEBA tariff is imposed on imports to the UK of a livestock-derived commodity, the price for that commodity increases along with UK production, and domestic use declines compared to the baseline. However, in contrast to this outcome, UK domestic use increases in the case of cereals, even when cereal imports to the UK are subject to a GEBA tariff. This occurs because of the increased UK demand for animal feed associated with additional UK livestock production when livestock-derived imports are also subject to a GEBA tariff. It increases use of both UK and imported cereals for animal feeds, along with imports of soymeal, and could have negative implications for environmental policies other than GHG reductions, such as improving water quality by maintaining or improving UK nutrient balances. The increased environmental pressures arise from the production of more animal manure and its application to farm land.

A GEBA tariff applied to UK commodity exports (livestock-derived and cereals) to foreign markets decreases UK prices and overall UK production, but increases UK use of domestically produced commodities, as some imports to the UK are displaced. However, if tariffs are applied to only a subset of agricultural commodities, for example, when livestock-derived commodities exported from the UK are subject to the tariff, but UK cereal exports are not, domestic use of cereals decreases instead. This is due to lower production levels in the livestock sector (decreasing feed demand) combined with no disincentive (GEBA tariff) to UK cereal exports. Although UK exports decrease (and in contrast to the scenario described in Finding Three), this results in a reduction in UK crop and livestock production compared to the baseline and has complementary impacts for nutrient balances, leaving these below the baseline level.

6.2 Final remarks

The analysis is illustrative but provides a vehicle to explore, in the context of UK agriculture, the impacts of intervening to discourage the movement of emissions embedded in commodities across borders. The results succeed in illustrating a number of issues, relevant to interventions that attempt to internalise emission-intensities within international competitiveness.

The GEBA inhibits carbon leakage (production moving from lower to higher emitting international competitors) and leads to a decrease in the global volume of emissions. It encourages production in the UK when it can produce a given commodity with relatively better emission-efficiency, and elsewhere when it cannot. However, this means that production (source) emissions are higher in the UK when it has a competitive advantage in emission-efficiency, while consumption emissions will be lower than the baseline level. The opposite is true when the UK is relatively less emission-efficient, with production emissions lower than baseline levels, but consumption emissions relatively higher. The impact on the UK agricultural source emission inventory would depend on the aggregate emissions efficiency of all domestically produced agricultural commodities that are also internationally traded. This has implications for how emission-reduction targets are defined, accounted for, and progress is evaluated. This analysis assumes average national emission-intensities are the same for the entire ten year projection period. However, if there was a movement towards greater convergence, or divergence, between the UK and RoW in terms of emission-intensity, then the costs and benefits to UK producers and consumers would change, as would the implications for source or use accounting frameworks in the UK emissions inventory.

Regardless of whether the UK is relatively more or less emission-efficient than the trading partner, the GEBA ultimately has a positive influence on emissions reduction – although the costs and benefits from changes apply unequally on producers or consumers. Consumers benefit from lower prices when UK exports are subject to the GEBA tariff, and although production does decline, increases in import volumes is dampened because some domestic supply is redirected from exports to meet UK demand. In the case when the GEBA tariff falls on imports, producers enjoy higher prices, and a stronger position in the domestic market. The potential interaction of protecting the domestic market can complement, or hinder, national emission reduction strategies, and would need to be considered carefully in the wider policy context.

A GEBA works against carbon leakage from the UK by avoiding substitution by the same commodity produced elsewhere – but with more embedded emissions. It also works in the opposite direction, discouraging UK production of high emissions-intensive exports from the UK. The application of this framework provided in this report does not vary the emission or tariff border adjustment across commodities. Therefore, the GEBA tariff itself does not change consumption/production to favour less emission-intensive commodity types, and price levels may adjust to maintain the competitiveness of domestic production in the UK market. This means changes to consumption and production patterns are driven by the UK's new trade position, which incorporates international carbon competitiveness. In this way, international trade can support national action to reduce emissions by reducing first mover disadvantage, as well as incentivising trade partners to do the same.

Appendix A. Baseline production, price and trade projections

The deterministic baseline provides a point of comparison, so that the impact of the scenarios can be illustrated. These baseline projections were generated using data available in October 2021. It is important to note that these projections are not a forecast, but are used to provide a reasonable business as usual scenario, against which to compare hypothetical changes, in this case a GEBA. They are provided here to give a point of reference – however the key element to focus on is the difference between the baseline and when a scenario is implemented, as reported in the main body of the document.

Livestock

Projected baseline prices for the livestock commodities within scope of the GEBA scenarios are shown in Figure *A-1*. Prices remain stable for pigmeat and poultry throughout the projection period. A gradual decline in price is noted in the initial years of the projection period for butter and cheese, whereas there is a much sharper decline in sheepmeat price during this time, as the market comes down from a period of record high prices, but remains well above the recent historic average. There is a gradual increase in beef price over the initial projection years before a stable equilibrium is achieved.

Production, domestic use and trade estimates for livestock commodities are provided in Figure *A-2*. Cheese production is largely steady throughout the projection period, following a noticeable increase in domestic use in the initial years. Butter production and domestic use are stable over the projection period and the UK continues to be a net importer of butter. There is a gradual decline in beef production throughout the projection period, whereas beef domestic use remains relatively stable. Sheepmeat production shows a declining trend over the projection period which is consistent with a decline in ewe numbers (Figure *A-3*). There is also a decline in sheepmeat domestic use, which is consistent with an anticipated decline in per capita consumption. The UK continues to be a net importer of pigmeat throughout the projection period. The baseline shows a gradual decline in pigmeat production and domestic consumption, which is reflected in falling sow numbers and decreasing per capita consumption. The baseline is suggesting that the UK will continue to see growth in consumption of poultry products throughout the projection period. This is reflected in an increasing trend in production and domestic use, with marginal net imports.

Breeding herd numbers are shown in Figure *A-3*. Total dairy cows, beef cows and sows show a gradual declining trend over the projection period. This is partly related to production levels, but also due to productivity trends in the projection period. There is a more significant decreasing trend noted in ewe numbers.

Dairy and meat per capita consumption is shown in Figure *A-4*. There is a declining trend noted in the per capita consumption of pigmeat, sheepmeat and beef. In contrast, the baseline projection shows a gradual increase in poultry per capita consumption[21]. Cheese and butter consumption remains stable. The factors used to project per capita consumption include population, a standard of living indicator (in this case real GDP per capita), as well as own and substitute prices.

[21] These trends are consistent with recent research, for example see Stewart, C. *et al* 2021 https://doi.org/10.1016/S2542-5196(21)00228-X

Figure A-1 Livestock commodity historical (2016 – 2020) and projected (2021-2031) prices

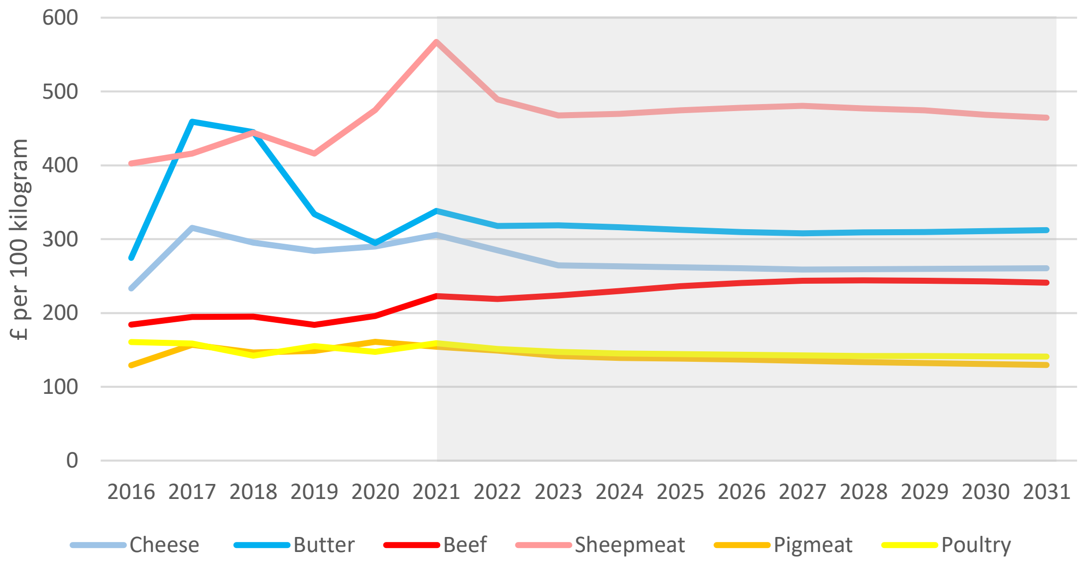


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Figure A-2 Production, domestic use and net exports of UK livestock products historically (2016-2020) and projected (2021-2031) in thousand tonnes

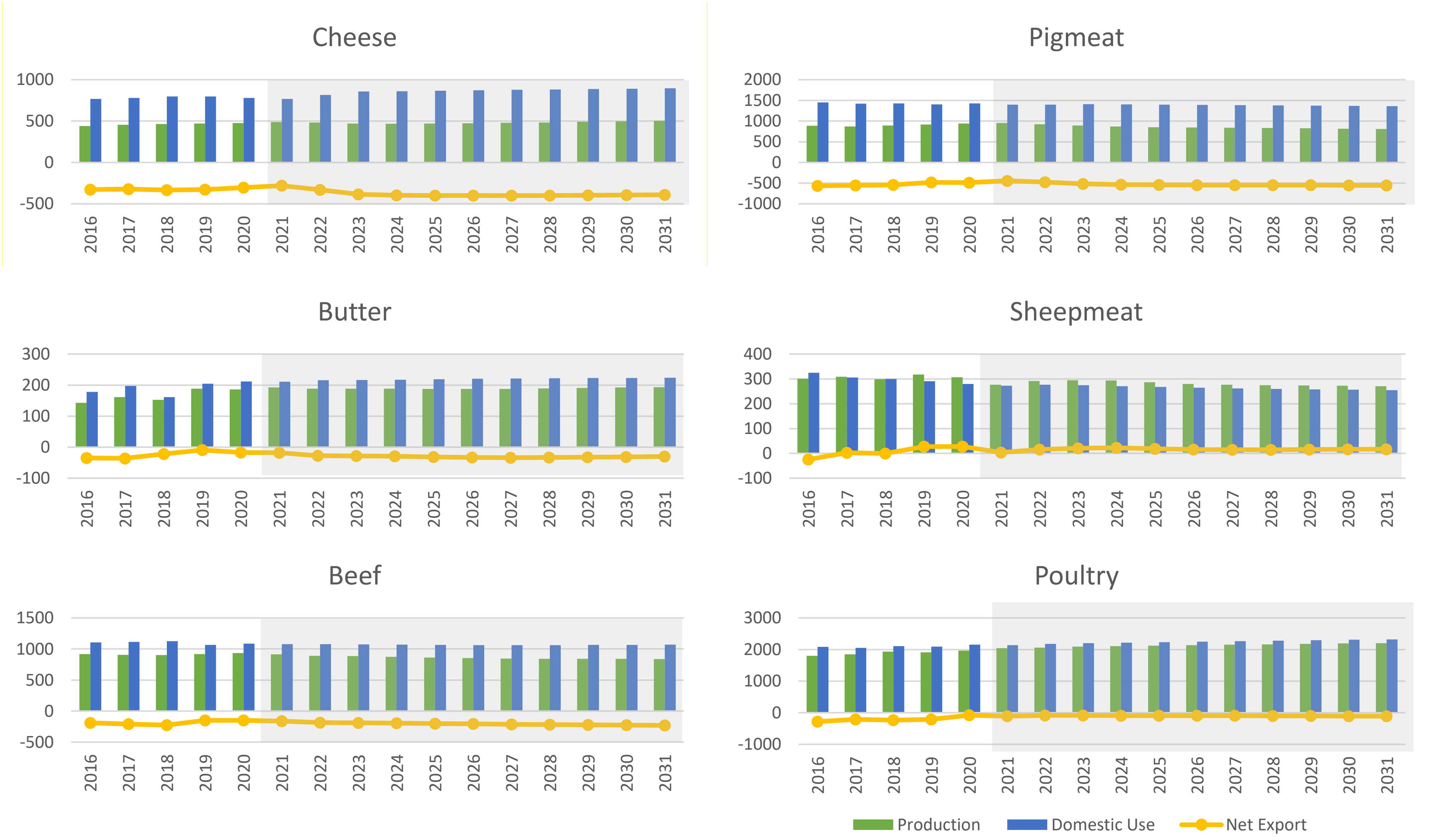


Figure A-3 Breeding livestock historical (2016 – 2020) and projected (2021-2031) numbers

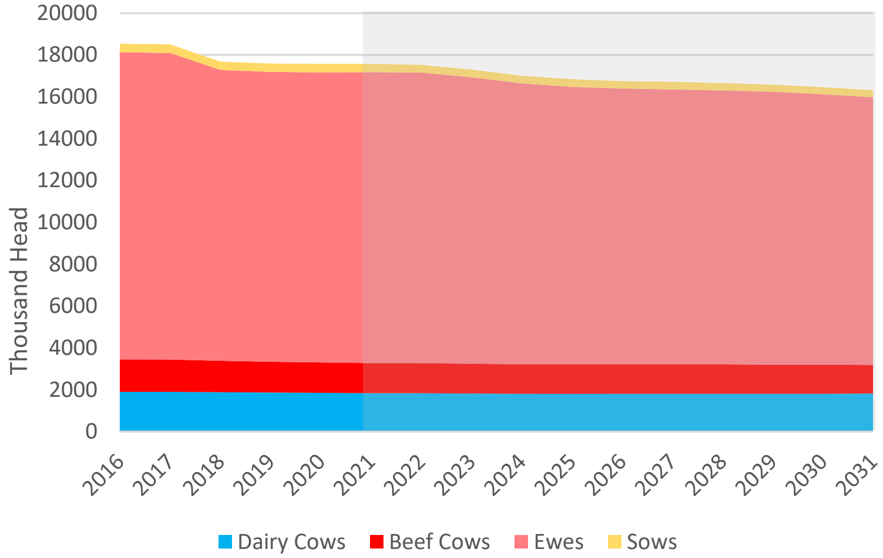
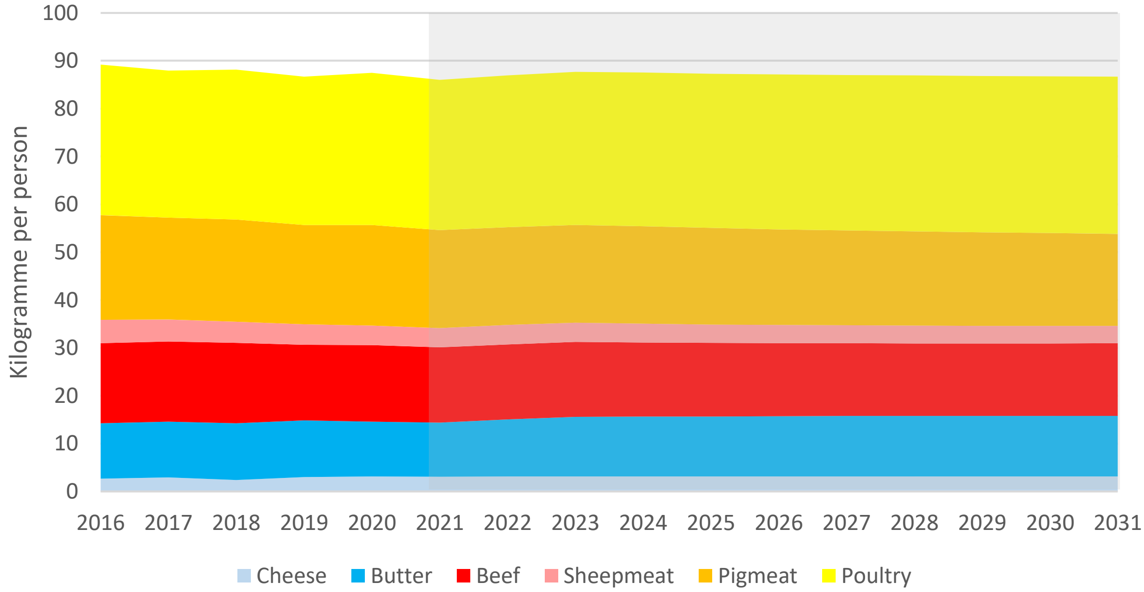


Figure A-4 Dairy and meat consumption per person in the UK



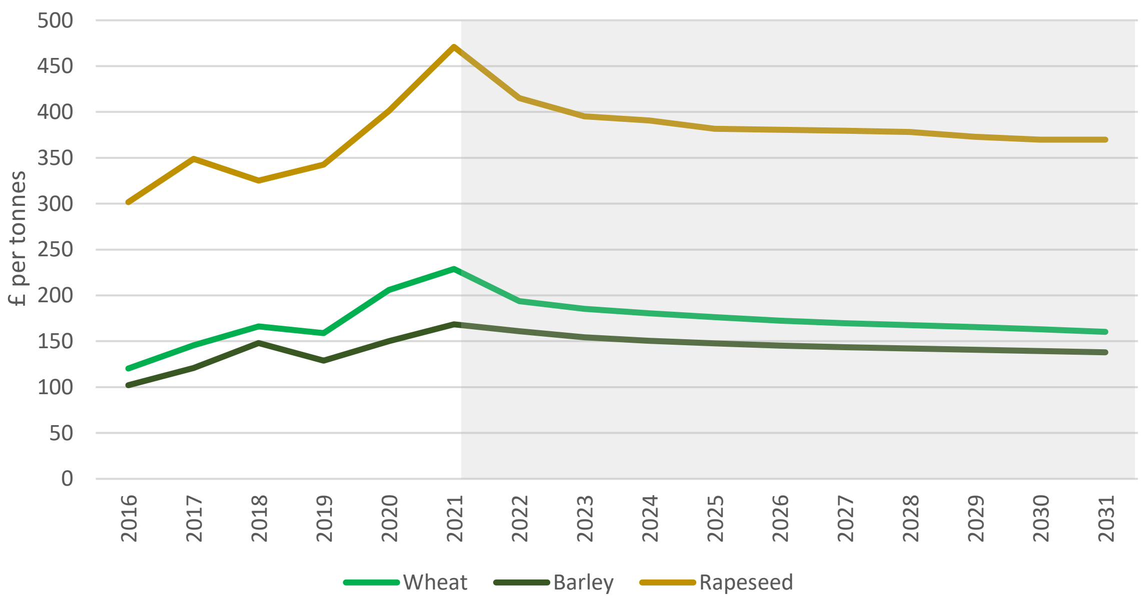
Cereals

Wheat, barley and rapeseed historic and baseline prices are provided in Figure *A-5*. Prices decrease over the projection period (from 2022 to 2031)[22]. In the historical period, the prices reached their peak in 2021 at £471 per tonne, £229 per tonne and £168 per tonne for rapeseed, wheat and barley respectively. This was related to tight cereal markets following poor harvests. The three trends follow the same dynamic over time. At the end of the projection period wheat and barley prices move closer together. UK crop area (Figure *A-6*) declines slightly over the projection period and wheat continues to account for the largest area. The recent rapeseed area is not maintained at historic highs going forward due to new pesticide regulations, but does recover somewhat in response to high prices. Oats show a gradual upward trend.

Historic and projected crop yields are shown in Figure *A-7*. It is assumed that technical progress will benefit yields, so these tend to increase over the projection period. The increase in average yields over the ten years is around half a tonne per hectare (a bit more for oats and less for rapeseed) due to anticipated improvement in farming systems, mechanisation and the introduction of more productive or new varieties of crops.

Figure *A-8* presents production, domestic use and net trade. The UK settles as a net importer of wheat over the projection period, although with a modest import balance. Barley exports consistently exceed imports, but production levels out below the recent historic peaks seen in 2019 and 2020. Rapeseed production remains well below pre-2019 levels, although there is some recovery over the projection period driven by strong prices. The UK remains a net importer of rapeseed, close to the 2020 position.

Figure A-5 Wheat, barley and rapeseed historical (2016 – 2020) and projected (2021-2031) prices



[22] This projection was generated before fertiliser, energy, and crop price spikes related to geopolitical events.

Figure A-6 Historical (2016-2020) and projected (2021-2031) UK crop areas

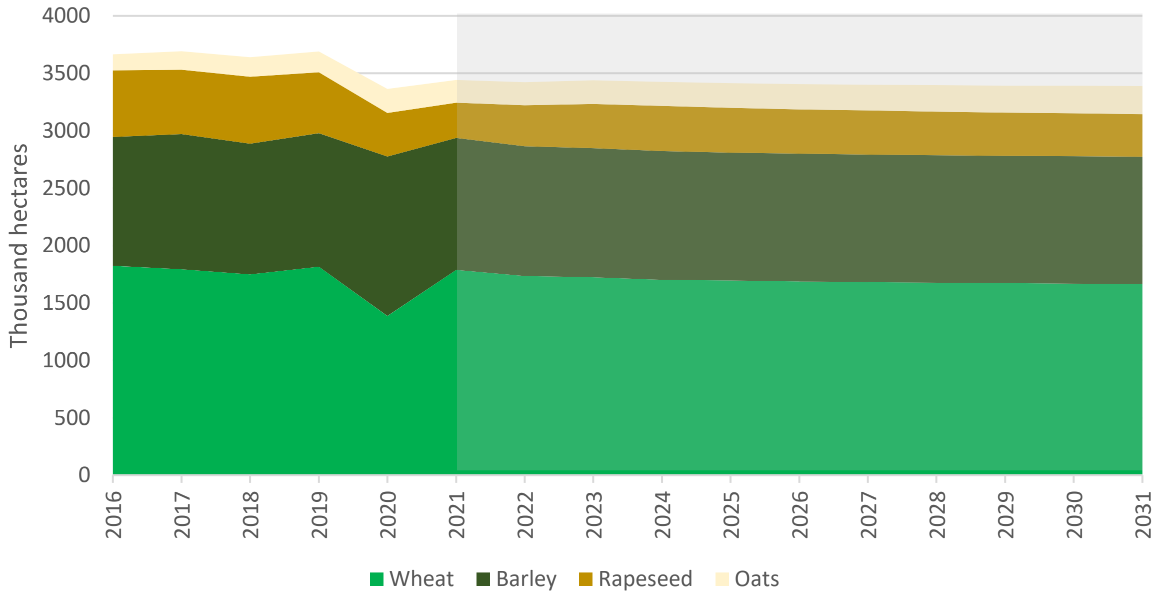


Figure A-7 Historic (2016-2020) and projected (2021-2031) crop yields

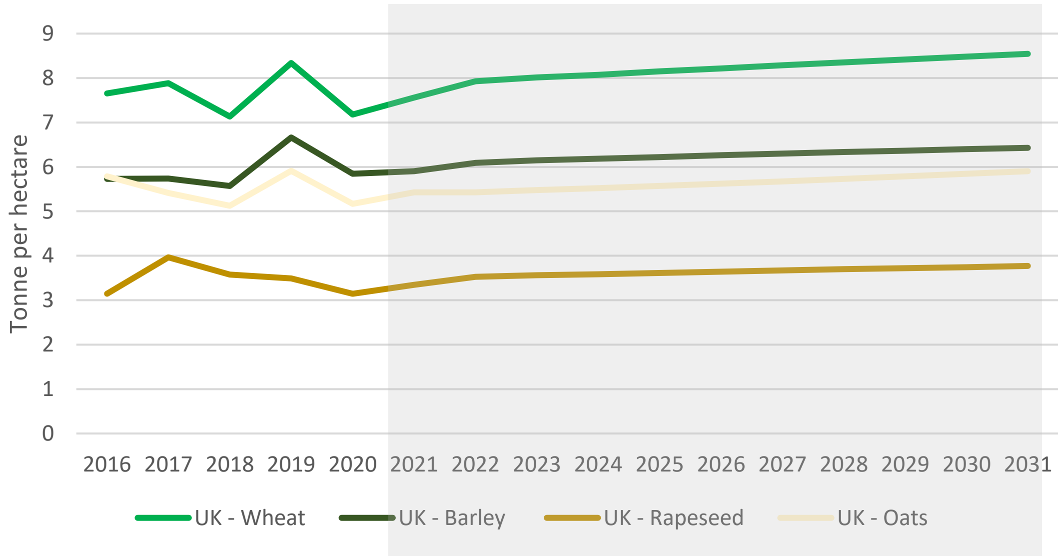
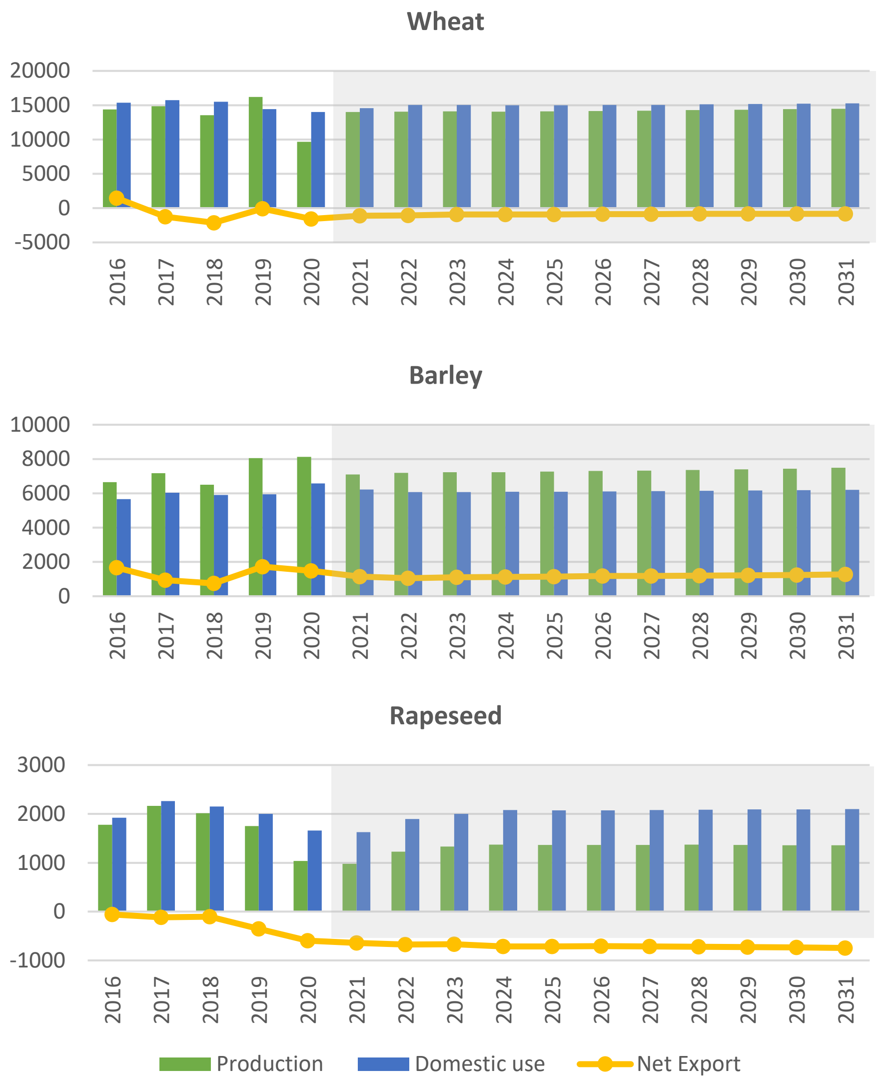


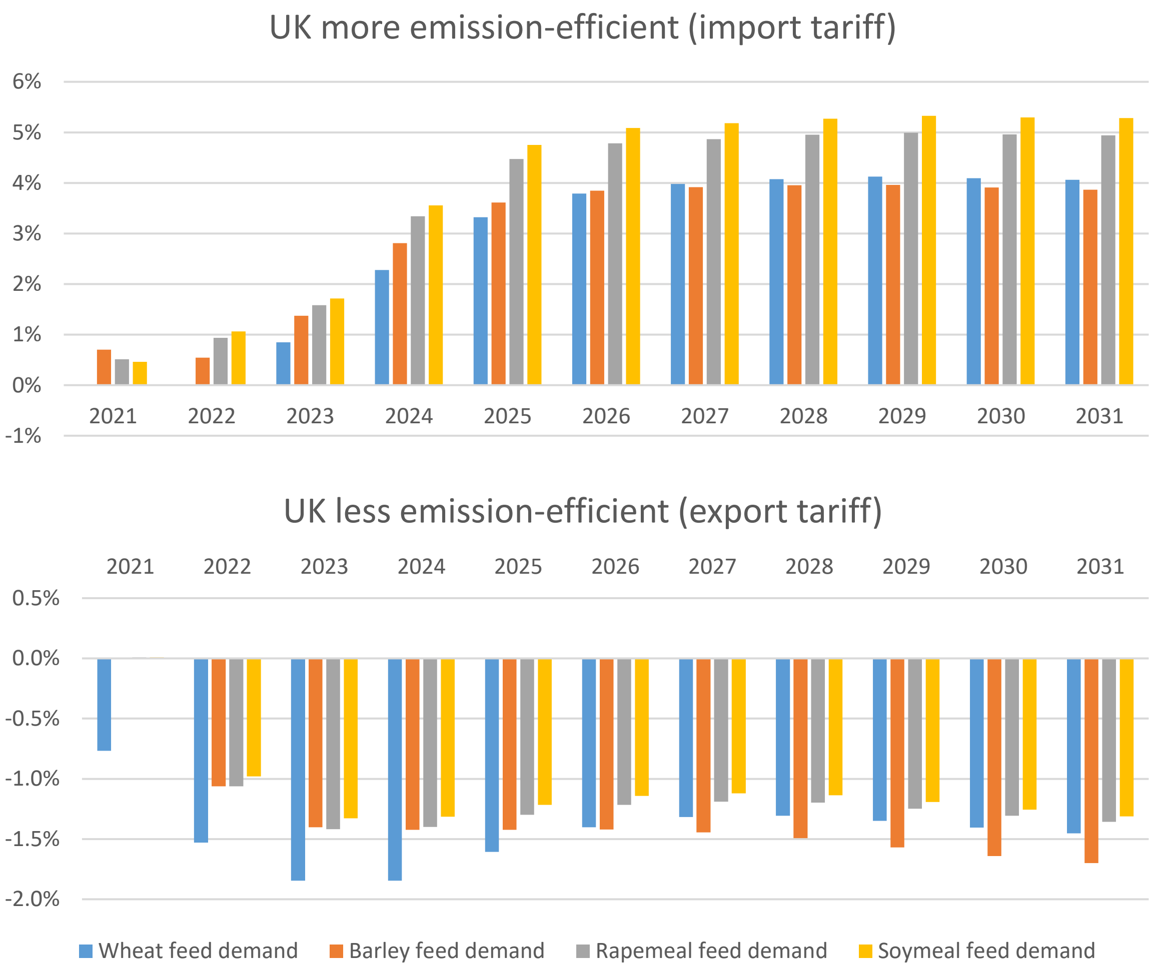
Figure A-8 Production, domestic use and net exports of UK crops historically (2016-2020) and projected (2021-2031) in thousand tonnes



Appendix B. Feed demand and nutrient balances

The percent change in feed demand when the UK is more or less emission-efficient in cereals and livestock commodities compared to the baseline is provided in Figure *B-1*. When the UK is less emission-efficient, there is a marginal decrease in UK feed demand for each scenario. When the UK is more emission-efficient, there is an increase in UK feed demand. The largest increase is in soymeal feed demand, at around 5% above baseline projected demand from 2025. The main reason for the response is an expansion in domestic production across all sectors.

Figure B-1 Percent change in feed demand from the baseline when GEBA implemented on cereals and livestock commodities



The FAPRI-UK Modelling System has been adapted to incorporate the inward and outward flow of nutrients to the UK agricultural system allowing a soil nutrient balance to be calculated[23]. Calculating a soil nutrient balance provides an indication of the impact agriculture can have on agricultural soils and the environment. By using a soil nutrient balance calculation in conjunction with the FAPRI-UK

[23] Details of the nutrient balance projection tool are provided in "Technical Note 2022-1: Projecting Nutrient Balances in the FAPRI-UK Modelling System" forthcoming on the AFBI website.

model, it can help demonstrate how particular policy scenarios can affect the economy and also the environment.

The nutrient balance calculation focuses on the most widely used nutrients applied to agricultural soils in the UK; nitrogen (N), phosphorus (P) and potassium (K). For the purpose of the investigation, the agricultural sector in the UK is treated a single system with the UK border as the system boundary for inputs and outputs:

- The main inputs of nutrients to the UK agricultural system are use of chemical fertiliser and also the nutrients contained within imports of agricultural commodities.
- The main output of nutrients from the UK agricultural system are considered to be contained within exports of agricultural commodities.

The nutrient content of agricultural commodities also was determined to allow the nutrients contained in imports and exports to be calculated. The baseline nutrient balances for N, P and K are provided, along with the balances when GEBA is applied to cereal and livestock commodities, in Figure *B-2*,Figure *B-3* and Figure *B-4*.

When the UK is more emission-efficient in the production of crops and livestock and a GEBA tariff is applied to UK imports, there is increased use of fertiliser and increased domestic production. In this scenario, the GEBA results in a trade-off of relatively higher nutrient balances with an increased surplus of N, P and K in agricultural soils. This could potentially lead to a negative environmental impact due to surplus nutrients in the UK agricultural system.

Conversely, when the RoW is more emission-efficient in the production of crops and livestock and a GEBA tariff is applied to UK exports, fertiliser use decreases due to a smaller crop area and a reduced feed demand due to relatively lower livestock production in the longer term. This has a beneficial impact on the UK nutrient balance with less fertiliser used.

Figure B-2 UK baseline nitrogen balance compared with UK more or less emission-efficient in crops and livestock

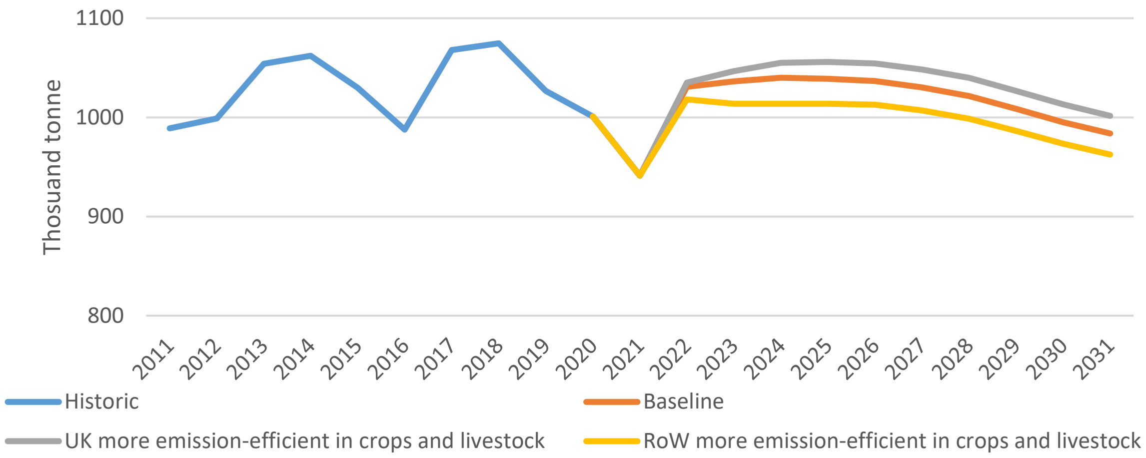


Figure B-3 UK baseline phosphorus balance compared with UK more or less emission-efficient in crops and livestock

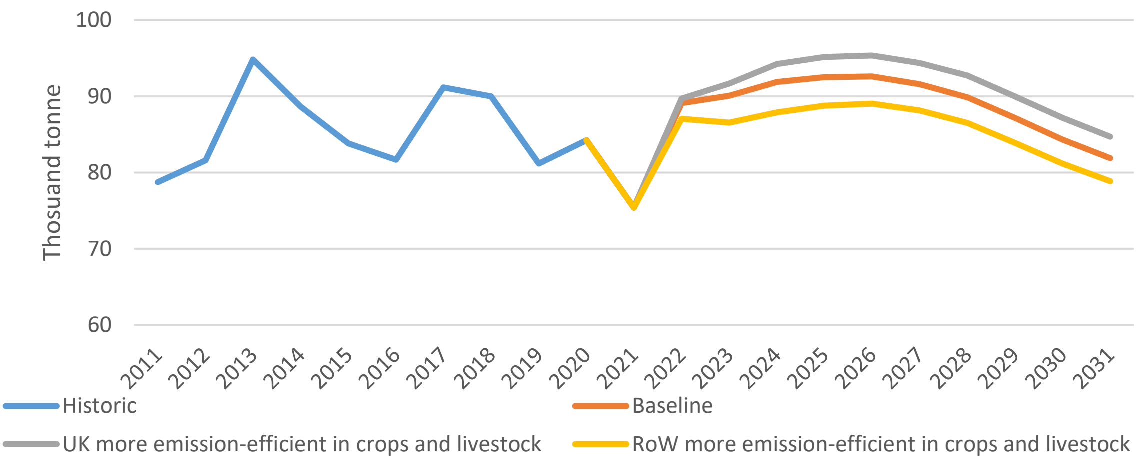


Figure B-4 UK baseline potassium balance compared with UK more or less emission-efficient in crops and livestock