Can diet change meet climate targets?

A trade story told with the UK Agricultural Market Model [1]

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Ruminant livestock produce more than half of the UK's agricultural greenhouse gas emissions, leading the Climate Change Committee to call for diets to move away from meat and dairy. We run simulations in Defra's partial equilibrium model of the UK's agricultural economy to evaluate how diet change might affect UK herd sizes and associated greenhouse gas emissions. We also simulate carbon tax and tariff policy scenarios to compare how diet shifts would interact with a widely advocated policy measure. We find unilateral diet change in the UK alone more likely to provoke a decrease in imports (and potentially an increase in exports) than bring about a significant reduction in UK ruminant herds and associated UK territorial greenhouse gas emissions. Conversely, our simulations find a large carbon tax imposed on domestic farmers alone reducing territorial emissions significantly, but only by leading to higher imports (and associated emissions) from overseas as UK consumption remains inelastic. Our modelling indicates that meeting the UK's agricultural greenhouse gas mitigation goals requires holistic action on the consumption and production side of the economy, with the UK facing unintended consequences in its agri-food trade balance if its climate ambition is not in harmony with its trade policy.

1. The agricultural greenhouse gas challenge

Emissions from agriculture made up 10% of UK greenhouse gas emissions in 2018, a total of 54.6 $MtCO_2e$. Over the next 20 years, agricultural emissions are projected to remain stable while other sectors' emissions fall. This would leave agriculture making up a larger and larger proportion of UK greenhouse gas emissions, rising to 13% by 2030 (BEIS, 2020). With the UK committed to net zero by 2050 (Gov.uk, 2019), agriculture will face more and more pressure to play its part.

The UK's previous 80% by 2050 target tolerated a certain amount of 'residual' greenhouse gas emissions. Under the net zero target, sectors with hard-to-halt emissions will be in competition with one another for access to sequestration. In positioning the sector as needing its residual emissions sequestered, agricultural industry voices (NFU, 2019) position the sector in competition with aviation (Sustainable Aviation, 2020) and concrete (UK Concrete, 2020) for a limited pool of technologically feasible greenhouse gas removal methods. The scale of greenhouse gas reductions required in agriculture thus rests on the

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scale of greenhouse gas removals available, their costs relative to agri-climate mitigation options and the relative competitiveness of agriculture compared to other sectors.

Table 1: Sector Emissions Mitigation Comparison

Sectors with hard to mitigate emissions	Sector GHG emissions, 2018 (% of UK GHG emissions)
Agriculture	54.6 MtCO2e, 10% (BEIS, 2019)
Aviation	39.3 MtCO2e, 7% (CCC, 2020b)
Concrete & cement	7.3 MtCO2e, 1.5% (UK Concrete, 2020)

The Climate Change Committee's further ambition scenario envisages land use change delivering an annual emissions sink of 2.5 MtCO2e by 2050 as major tree-planting programmes only just offset emissions from peatland (CCC, 2019). Remaining greenhouse gas removals rely on the mass rollout of novel Carbon Capture and Storage (CCS) technologies. For some industries like cement these are direct at source but for aviation and agriculture they would be separate offsets, a total of 53 MtCO2e per year of greenhouse gas removals in 2050 in the 'further ambition' scenario. (CCC, 2019). Combined agriculture and aviation emissions would need to fall by 47% by 2050 to meet this tight budget, assuming they are the only sectors needing to be accommodated. Greater falls would be required if CCS ambition were not delivered.

Cattle and sheep

Cattle and sheep contribute the majority of agricultural greenhouse gas emissions. At a global level, 73% of global agricultural greenhouse gas emissions can be attributed to ruminant livestock production. A further 6% can be attributed to non-ruminant meat (OECD, 2019). In the UK, cattle and sheep were responsible for 57% of greenhouse gas emissions from agriculture in 2018 (see figure 1).

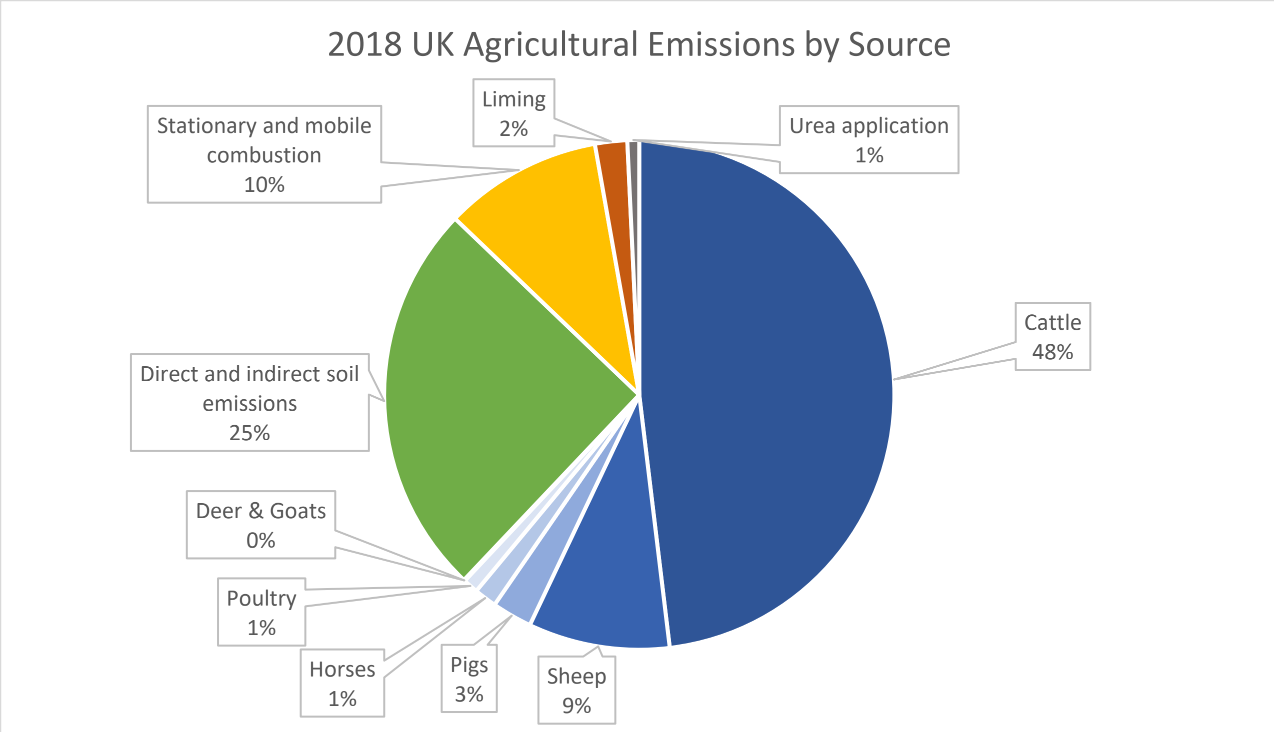

Figure 1 **sources of UK agricultural greenhouse gas emissions in 2018. Source: Defra.**

Emissions from cattle and sheep come from a variety of activities associated with livestock farming. Of all agricultural greenhouse gas emissions, 53% are methane emissions from enteric fermentation, part of the digestive process of cattle and sheep. Wastes and manure management generate 16% of agricultural greenhouse gas emissions.

Options to reduce these emissions can broadly be broken down into three categories: productivity, carbon intensity and quantity produced. Productivity measures decrease the number of animals required to produce a tonne of product, for example by breeding animals with more meat or increasing milk yield. If fewer emitting animals are used to produce the same quantity of animal products, this reduces emissions. If this improves the sectors' competitiveness enough to stimulate an increase in animal numbers, it can increase emissions. Intensity measures like improved manure management or feed additives reduce the amount of emissions per animal. Reducing the overall quantity of production reduces the number of animals needed, reducing emissions. The existing Defra greenhouse gas emissions from agriculture indicators (Defra, 2020b) all seek to improve productivity or reduce carbon intensity rather than reduce livestock production.

Table 2: Breakdown of Defra's GHGs from Agriculture Indicators

Mitigation measure	Reducing production	Reducing carbon intensity	Increasing productivity
Defra greenhouse gas emissions from agriculture indicators		Livestock nutrition (indicator 2) Manure management (indicator 9)	Breeding regimes (indicator 5) Milk yield (indicator 6)

CCC-commissioned research by SRUC, ADAS and Edinburgh University found a maximum technical abatement potential of 5.4 $MtCO_2e$ annually by 2050 for a similar set of measures (CCC, 2019). Assuming 100% uptake by farmers and that the overall level of agricultural activity remains unchanged, this represents just under 10% of greenhouse gas emissions from UK agriculture and residual emissions of 49 $MtCO_2e$ per year. This is only a few megatonnes below the 53 $MtCO_2e$ of industrial greenhouse gas removals available annually in 2050 from carbon capture and storage in the CCC 'further ambition' scenario. With the carbon budgets looking this tight and agriculture facing tough competition from other sectors for atmospheric space, it would seem prudent to investigate the potential for emissions savings through reductions in production.

What role for meat and dairy consumption?

A shift in diets away from meat and dairy has been highlighted by national and international organisations as a means to reduce greenhouse gas emissions from agriculture (UNEP, 2020; CCC, 2020). Some analysis on the potential impact of reductions in consumption demand for high emissions products has assumed changes in per person demand pass directly through the agricultural economy to result in proportional changes in production. From an economic standpoint this represents a 'closed economy' approach, but the picture is complicated by international trade. In an open economy where trade is accounted for, changes in demand affect the trade balance. The UK's agri-food economy is highly open to international trade and this could have a major effect on whether changes in consumption pass through to UK production or instead reduce imports, for example. The trade balance is one of the most dynamic parts of the agricultural economy; assuming it to be fixed omits critical dynamics and leads to incorrect conclusions.

In this paper we use Defra's UK Agricultural Market Model (UKAMM) to analyse the potential impacts of changes in UK meat and dairy consumption in a way that takes account of international trade. Changes in diets would not take place in a static agricultural sector: they would impact a sector in transition to Net Zero. To account for this we assess what impact a production-side carbon tax would have on UK agriculture and then assess how this might interact with a change in consumer preferences for meat and dairy. We examine gradual reductions in demand of 10%, 20%, 35% and 50% by 2030. We examine how these changes would interact with both domestic-only carbon taxes and with border carbon taxes applied on imports. We do not examine the potential impact of carbon taxes on productivity or carbon intensity, focussing solely on the role these policies would have in dissuading production of higher-carbon products.

2 Literature Review

2.1 Carbon Pricing, Carbon Leakage and Carbon Border Adjustments

Carbon pricing, emissions trading and carbon taxes are not only widely discussed but widely implemented climate mitigation policies (World Bank, 2021b). So far these measures have affected agriculture indirectly, for example through energy and fertiliser costs, rather than being directly applied to agricultural emissions. The empirical literature on carbon pricing in Europe has focussed on the EU's Emissions Trading Scheme, which was the first implemented in the world. (Martin et al, 2016) reviews work on the early years of the EU ETS, which finds a small but notable impact in abating EU-wide emissions over that period. (Verde, 2020), in their review of the literature on the carbon leakage effects of the EU's ETS find that there is little, primarily driven by the price of carbon turning out to be too low to drive such effects. Indeed, the same paper finds that the price was also too low to have any significant effects on the competitiveness of firms under the ETS scheme. As one might expect, (Martin et al, 2016) also report that the abundance of carbon quotas and the low price of carbon in the EU's ETS have also done little incentivise innovation. (Martin, Muuls and Wagner, 2013), through interviews with firm managers, found there to be little difference in the process and product innovation of firms that were covered by the ETS and those that weren't. However, (Borghesi, Cainelli and Mazzanti, 2012) find evidence form their large study of Italian firms that participation in the ETS may be positively correlated with broad environmental innovation, but that this may be counteracted by a negative correlation with the proportion of sectoral emissions accounted for in the ETS quota allocation. Empirical studies into the effects of the EU's ETS have been limited, however, to the first two phases of the scheme by the availability of data, during which time the price of carbon was considerably lower than it has risen to in recent years.

The apparent lack of the EU ETS' effectiveness has left a requirement for ex ante literature that considers alternative policy formulations, particularly when it comes to agriculture which currently isn't included in the EU or UK ETS. The simulation literature on carbon pricing has focussed on broad, global Computable General Equilibrium model approaches, which by nature cover multiple sectors and multiple countries. (Carbonne and Rivers, 2017) reviewed the CGE literature on the impact of broad environmental regulations, finding that, on average, the literature finds that a 20% carbon abatement objective leads to a 5% reduction in output of so called EITE sectors (energy intensive and trade exposed). Partial equilibrium models allow for a higher commodity resolution within a specific sector, and allows for more detailed consideration of a national context. However, partial equilibrium models may not always be effective at capturing the effects of carbon pricing on innovation or be able to completely capture the international carbon abatement effects. They are effective at identifying where market disruptions may be concentrated at the commodity level. Such detail is significant when considering food markets, which are uniquely sensitive in the public eye and uniquely important to consumer wellbeing. (Mathiesen and Moestad,

2004) demonstrated how a partial equilibrium model can allow of substitutions within a supply chain, which can significantly reduce the carbon leakage estimates of a carbon price.

Simulation modelling is always contingent on its assumptions, and as (Branger and Quirion, 2014) note, the Armington elasticity assumed plays a significant role in determining the carbon leakage effects in the CGE literature. PE models also rely on Armington assumptions to determine how responsive international trade flows are to policy shocks in individual countries or regions. This is particularly important for the study of Carbon Border Adjustments (import tariffs based on the carbon footprint of the imported good), which seek to abate carbon leakage, however, have not yet been implemented anywhere in the world, and thus rely on simulation modelling. (Branger and Quirion, 2014) conduct a meta-analysis of CGE CBA modelling and find that they reduce carbon leakage ratios by an average 6 percentage points. This is a smaller effect than we find in our results. In part this may be due to the sectoral limits of our partial equilibrium model, however it may also be due to the implied Armington elasticity between domestic UK production and imports in supplying UK consumption in UKAMM. We assume that imports can adjust quickly to price signals, whereas domestic production, particularly in the beef sector, is limited by the length of animal lifecycles. Whilst UKAMM doesn't explicitly employ Armington elasticities, our assumptions lead to imports responding more quickly to a carbon import tariff than domestic production to a domestic carbon tax in our results.

2.2 Diet Change

Studies to date estimating the environmental benefits of reducing meat and dairy consumption have tended to assume either simultaneous global shifts in diet, or unilateral shifts with very strong trade assumptions. (Stehfest et al, 2009) use the IMAGE integrated assessment model to assess the impacts of hypothetical shifts to a variety of alternative diets, implementing each diet globally. (Poore & Nemecek, 2018a, 2018b) use updated versions of these multilateral diet shift scenarios in the same model. OECD (2019) model a global reduction in meat and dairy demand in their Aglink-Cosimo model. All these studies find simultaneous global reductions in meat and dairy consumption leading to a major reduction in agricultural greenhouse gas emissions. Analysis of the potential impact of a reduction in UK meat and dairy consumption has tended to assume demand reductions would equally impact the domestically produced and imported segments of UK meat and dairy consumption (NFS 2021, p.54; CCC 2020a, p.49). As we will argue in this paper, the UK's meat and dairy trade balance has historically been more sensitive to changes in demand than the level of domestic production, meaning unilateral reductions in UK meat and dairy demand may lead to adjustments in the trade balance before adjustments in domestic production levels.

The historical responsibility for greenhouse gas emissions is not evenly distributed between states. This is enshrined in UN climate negotiations as the principle of "common but differentiated responsibilities" (UN, 1992). Trends in diet composition and food availability are not evenly distributed either, with OECD-FAO projections envisaging substantial increases in global demand for meat and dairy in developing countries over the next decade (OECD, 2021). With meat and dairy consumption significantly higher in developed countries like the UK that bear greater historic responsibility for greenhouse gas emissions, it seems reasonable to assume that the UK might be expected to be one of the first movers in reducing meat and dairy consumption. This means any reductions in UK demand for meat and dairy would likely come in the context of the expansion of global animal products markets. This paper seeks to expand on the current literature by using the UK Agricultural Market Model to simulate the impacts of a first-mover, unilateral UK diet shift in the context of unchanged dietary trends in the rest of the world.

Current consumption trends

This analysis will examine hypothetical, unforeseen reductions in meat and dairy consumption. But first we will present a brief summary of the evidence around existing trends in UK meat and dairy consumption.

Dairy products are present in most consumer's baskets with 94% of UK households buying a dairy product in an average week (Kantar, 2020) However, the rise of plant-based dairy is a substantial force which is driving growth and change in the dairy sector, with Alpro (a plant-based dairy alternative) being ranked as the third most popular 'dairy' brand in the UK in 2019.

The Family Food module of the Living Costs and Food Survey (Figure 1) (Defra, 2020c) shows that, on the whole, milk consumption has declined over the past 40 years. However, since 2013 to 2019, milk consumption has somewhat stabilised with year on year percentage change varying between -2 and 3%. Despite this, within Europe, the consumption of milk is under pressure, but demand for cheese is expected to grow at a moderate pace. Within the European total dairy market, dairy alternatives have a share of 3% and the category has experienced annual growth rates of around 8% since 2010 (ING Research, 2020)

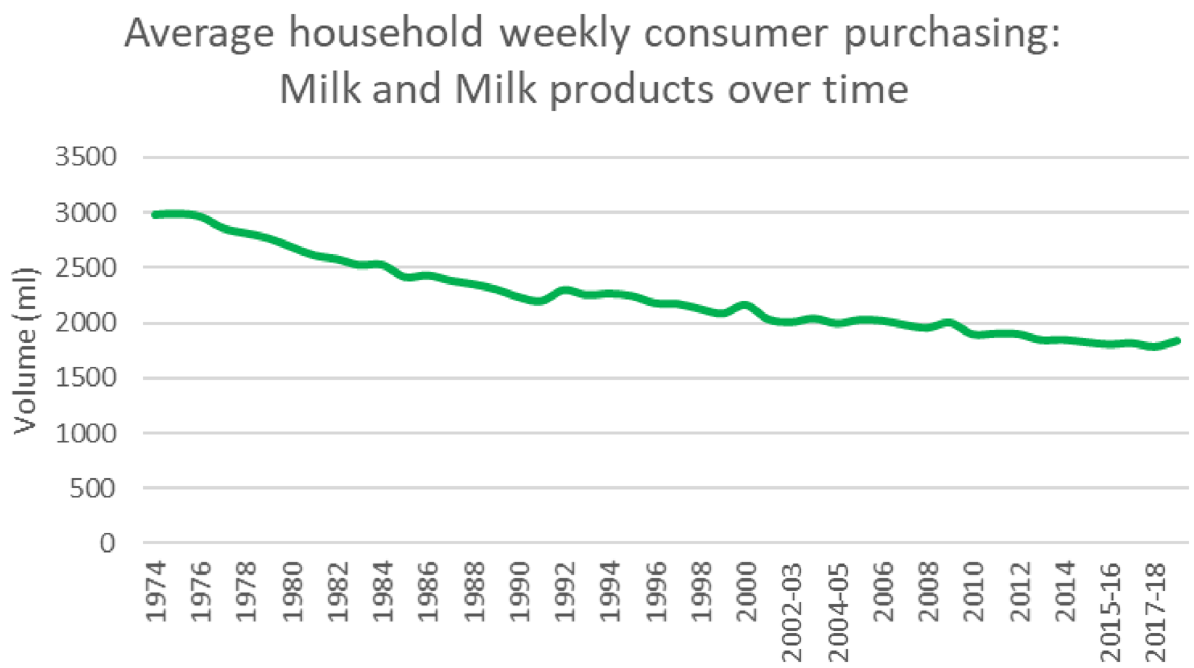

Figure 2 ***Living Costs and Food Survey***

The household purchasing of dairy alternatives has been steadily increasing in popularity since measurement began in 2004-05. There was a 71% increase in the purchasing of non-dairy alternative drinks from 2015-16, to 2018-19, however, growth in consumer purchasing is slowing down with only a 5% increase in household purchasing in 2018-19 from the previous reporting year (Defra, 2020c).

The National Diet and Nutrition Survey has observed few changes over the last 9 years in meat consumption, although a downward trend in consumption was noted in the intake of red and processed meat (NDNS, 2019)

The Family Food module of the Living Costs and Food Survey (Defra, 2020c) [2] shows that consumption has declined considerably over the last 40 years, with weekly consumption continuing to significantly decline from 2015-16 to 2018-19. There have been significant reductions in the weekly volume of minced beef, mutton and lamb, and lamb chops.

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[2] Carcase meat includes beef, mutton, lamb and pork

However, consumers are not necessarily reducing their total meat intake - the evidence is mixed. According to the same survey, the weekly household consumption of non-carcass meat and meat products[3] has shown an upwards trend, with weekly consumption having significantly increased since 2015-16 to 2018-19. In particular, we have seen a significant 15% increase in the weekly household consumption of chicken in this time period.

Meat substitutes like plant-based burgers and sausages accounted for around 1.4 billion EUR in retail sales in the EU and the UK in 2019. The category has seen double digit growth over the last decade but still only accounted for 0.7 percent of total meat sales in 2019 (ING Research, 2020). Since then vegan options have become increasingly prominent on the UK high street with brands like Greggs, McDonalds, KFC and Burger King launching vegan ranges (BBC, 2021). It is not yet clear what impact this will have on the data.

3 The UK Agricultural Market Model

Defra uses the UK Agricultural Market Model (UKAMM) as ‘another expert in the room’: it is one of a plurality of analytical approaches used to understand the agricultural economy. In this report UKAMM provides our framework, but its findings are complemented with qualitative, historical and sociological evidence to contrast, verify and caveat our simulations. They are explained in full depth in the model’s documentation (Defra, 2021) and we explain them as we go where relevant in our analysis, but we will also explain a few general limitations here.

UKAMM bases its projections on past economic conditions, behaviours and dynamics. This gives it a rich picture of the types of production that have dominated UK agriculture in recent decades. But as changes proposed become more transformational, a model based on past data like UKAMM becomes less useful. It does not have this same rich picture for new, innovative and potentially disruptive foodstuffs. These means that we cannot have a well-developed picture of how alternative plant-based, insect or even lab-grown proteins might be substituted for a fall in demand for higher emissions animal products. The analysis of the sectors in decline will be limited by our inability to foresee how they will interact with the sectors that will displace them. For similar reasons UKAMM only simulates until 2030. Beyond that point uncertainty around the shape of the UK agricultural sector poses great challenges to the reliability of a historically-calibrated market model like UKAMM.

UKAMM models the relative competitiveness of UK goods with imports but its complexity is limited, assuming, for example, that the UK economy does not affect world market prices. This means the model may somewhat overstate the degree to which UK goods are exported overseas if UK prices fall. Supplementary analysis using other models can help assess how important an effect this assumption has in each scenario. This assumption also means UKAMM is better placed to examine a unilateral change in demand rather than a multilateral

[3] Non carcase meat and meat products include liver, offal, bacon, ham, corned beef, cooked meats, canned meats, chicken, other poultry, sausages, burgers, ready meals, pate, meat pastes, takeaway meats

one. (For multilateral analysis see OECD, 2019.) The model does not capture any reallocation of resources between agriculture and other sectors. This means it will not account for any shifts in emissions that were to result if spending on high emissions foodstuffs were instead redirected to non-agricultural consumption such as holiday travel or home energy efficiency improvements.

Baseline Projections

To be able to estimate the potential impact of a change in consumption, we need a counterfactual baseline scenario against which to compare the results of our analysis. Defra's UKAMM team maintains a baseline scenario reflecting the state of agriculture today and the state of agricultural policy as set out in law. It does not include policy proposals currently in development, even if already announced by the government. The current baseline scenario assumes the EU Trade & Co-operation Agreement poses modest barriers to agri-food trade between the UK and the EU as well as assuming the agricultural subsidy regime and farm payments remain largely decoupled from production volumes. The new Environmental Land Management Schemes will change agriculture in England, but until we know exactly how it will not be factored into our baseline scenario.

Population growth is a key factor in total UK agri-food consumption and is factored into our baseline. Population has consistently grown year-on-year since the 1980s and the ONS projects it to continue to grow over the next decade (ONS, 2020). In our simulations this will counteract some of the downward pressure on per capita UK consumption.

Figure 3 shows historic data from 2008 to 2019 and UKAMM's projected meat and cheese consumption in our baseline scenario for 2020 to 2030. Consumption is relatively stable for pigmeat, beef, cheese and sheepmeat but shows a marked increase for poultrymeat.

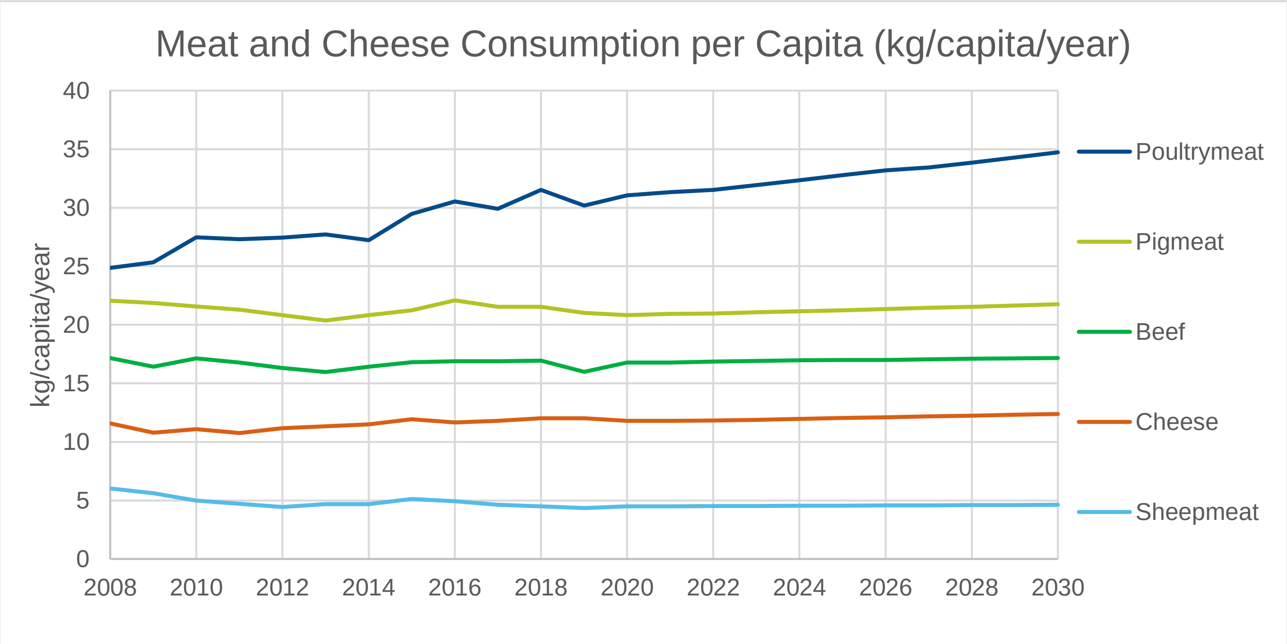

Figure 3 ***meat and cheese consumption per capita in our baseline scenario, based on historic trends***

4 Scenario Results

4.1 Carbon Tax

In these scenarios we use the UK Agricultural Market Model (UKAMM)[4] to examine the impact of a hypothetical carbon tax on the production of meat and dairy commodities in the extreme case that producers take no carbon mitigation measures in response. This means that farmers only have a choice between paying the tax and reducing production – they have no possibility of improving carbon intensity of production. There is no trading and carbon tax revenues are spent outside the sector. In the first set of scenarios, the carbon tax is applied to domestic producers only. Consumers can avoid the tax by substituting to imports. In the second set of scenarios the carbon tax is applied on imported products as well. These scenarios act as a proxy for policies that require livestock farmers or exporters to implement costly greenhouse gas mitigation measures. They will allow us to examine the impact of diet change in the context of the agricultural transition.

Here we report on the following scenarios:

0. Baseline: no carbon tax
15. Carbon tax of £15 per tonne CO2e applying from 2020
    a. to UK production only
    b. to UK production and imports (additional to existing tariffs)
50. Carbon tax of £50 per tonne CO2e applying from 2020
    a. to UK production only
    b. to UK production and imports (additional to existing tariffs)

This modelling gives us an upper bound for the scale of impact a carbon tax might have on UK meat and dairy production, consumption and net trade. It gives an estimate for the potential reduction in greenhouse gas emissions achieved by disincentivising the production of high carbon commodities in this way. We report on the difference between annual emissions in 2030 projected in our baseline scenario and in our intervention scenarios.

This modelling can't tell us what potential impact a carbon tax might have on agricultural greenhouse gas emissions as we do not have enough information about how farmers might implement mitigation measures in response or the potential for carbon efficient farms' market share to displace less carbon efficient farms. Nor can it tell us about non-market responses to the tax – be it GHG monitoring, new policy interventions, farmer outrage or consumer virtue signalling.

[4] For general information about the UK Agricultural Market Model, its assumptions and data sources, see the model documentation: https://www.gov.uk/government/publications/uk-agricultural-market-model-ukamm

Carbon border tax scenarios

Carbon border adjustment mechanisms are being explored by a range of countries and international blocs, most notably the European Union. These policies envisage charging a tariff on imports relative to the greenhouse gas emissions emitted in the production of the commodity. This would mean that domestic producers required to meet the costs of climate mitigation policies like the Emissions Trading Scheme would not lose market share to overseas producers not subject to similar policies and their associated costs. The European Commission characterise this as ensuring that “price of imports reflect more accurately their carbon content”. (European Commission, 2020)

Our modelling applies a border tariff proportional to UK sector average carbon emissions to imports of animal products, just as applied to domestic production. A key caveat to this analysis is that there is already a complex set of tariffs and non-tariff measures regulating agricultural trade and the interaction with these would have to be carefully considered in policy design. In our scenario, carbon tariffs were imposed over and above already costly tariff rates. Specific analysis would be needed to assess any proposal for carbon border adjustment mechanisms to replace existing tariff rates.

Table 3: Summary of Key Scenario Assumptions

Summary of key assumptions	Implication
No differentiation between carbon efficient and carbon inefficient producers. Production in each commodity is taxed the same based on UK industry average emissions, both for UK produced and for imported goods.	In reality carbon efficient farms could pay less tax than carbon inefficient farms, potentially gaining in market share and displacing some lower carbon production. This may change the impact on greenhouse gas emissions and production.
Consumers do not substitute to lower-carbon protein alternatives.	If consumers did start substituting en masse to non-animal proteins the impact of lower meat and dairy consumption volumes would be greater.
The farming sector does not implement any carbon mitigation measures in response to carbon tax	In reality the farming sector may be able to avoid paying some of the carbon tax by implementing carbon saving measures. This would reduce emissions and may lessen the impact on production if farmers spend less on mitigation measures than they would have had to pay in carbon tax.
Unilateral carbon tax only applied by UK.	If other countries implement similar measures, then this would dampen the carbon leakage effect.
Carbon import tariffs on top of existing tariffs regime.	In reality a carbon tariff could replace the rationale for the existing tariff regime rather than being additional to it.
Carbon tax applies as a 1:1 negative hit on farmers' returns. They continue responding to changes in their returns in the same way they have done in recent years.	In reality farmers may perceive a new tax differently depending on how it is communicated and social expectation forming processes. Elasticities based on farmers' historic responses to changes in returns may not reflect how farmers adjust production in response to a carbon tax.
Tax revenues generated are spent outside of the sector.	In reality tax revenues might be used on programmes that improve farms' carbon efficiency, lowering how much tax they pay and dampening the impact on production.
Carbon tax applies at full rate from 2021 and does not increase or decrease during that time.	In reality a carbon tax might be implemented gradually. Sectors like beef take time to adjust so the impacts of a decade of a £50 carbon tax would be more dramatic than carbon taxes gradually increasing from zero to £50 over ten years.

Summary findings

We find that a £50/tonne carbon tax on domestic production alone yields a 10% decline in annual UK territorial greenhouse gas emissions from beef production in 2030 through decline in herd sizes. If no policy is implemented to prevent carbon leakage and consumer demand remains at baseline levels, imports increase and consumption falls to just below baseline levels.

We estimate that a £50/tonne carbon tax on both imports and domestic production would decrease annual emissions from beef production by 5% in 2030 but no emissions are offshored; instead UK beef imports fall by 15%. Similar but smaller impacts are projected for sheepmeat and dairy.

Placing a carbon tariff on imports decreases the reduction in UK territorial greenhouse gas emissions but has a greater overall effect on global emissions by stopping carbon leakage.

In the most impactful scenario (50b), GHG emissions from UK beef, dairy, sheep, pig and poultry production and imports are 7.5% lower than they would otherwise have been in 2030.

Beef

The average sector carbon intensity of UK beef production is the highest of the livestock commodities in scope, so the value of the carbon tax levied is the highest per kg produced. This is reflected in the results, which are most dramatic for beef. Emissions from beef cattle decrease by more than might be expected as more of beef demand is met from ex-dairy cattle; this is counteracted by a smaller than expected decline in dairy cattle emissions. In this scenario there is very minimal change in beef producer prices.

Figure 4 shows the difference between the annual figure for 2030 in the intervention scenario in question and in our baseline scenario.

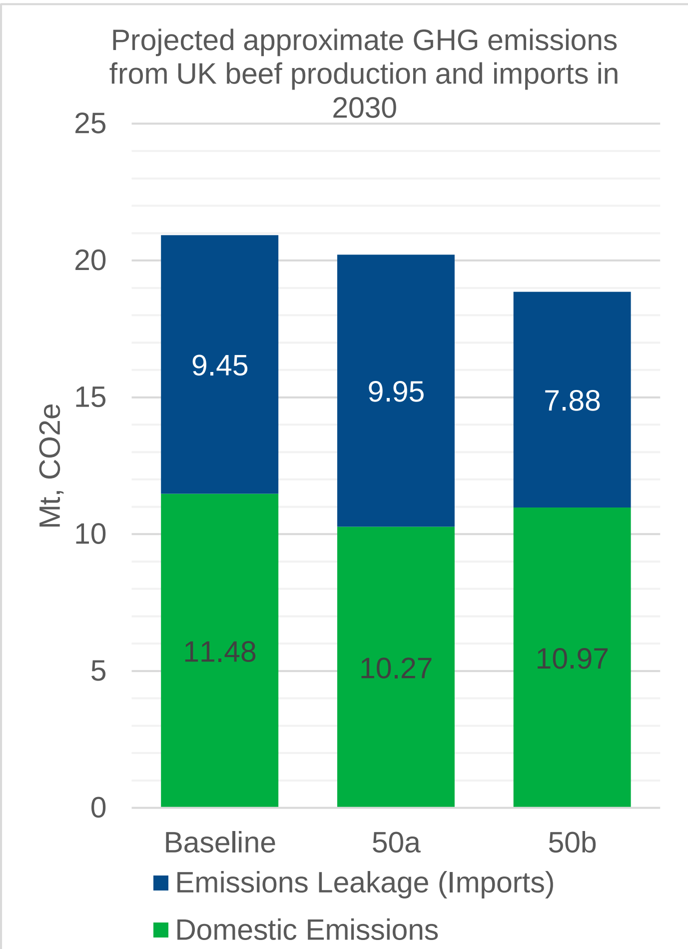

Figure 4 Projected approximate GHG emissions from UK beef production and imports in 2030 under baseline UKAMM projections, a domestic carbon tax of £50/tCO2e (50a) and an additional equivalent carbon tax on imports (50b).

When a carbon tax is levied at the border, domestic emissions are higher than they would be if the tax was levied in the UK alone. This increase is more than offset by the reduction in imports, meaning the UK's contribution to global emissions is likely to be lowest in this scenario, unless imports are significantly less carbon intensive than UK production. Overall there is a significant reduction in beef consumption when £50 per tonne carbon taxes are modelled as applying on both domestically produced and imported beef, leading to 22.5% increases in producer prices.

Sheep

Similar, albeit more modest, effects are seen in the sheep market. After cattle, sheep are the most emissions intensive livestock in the UK.

A £15 per tonne carbon tax is modelled as having negative effects on production and emissions buts a £50 per tonne carbon tax levied on domestic production is simulated as depressing production by 5%. Imports rise by 5% to satisfy inelastic consumption demand (Scenario 50b in figure 5). In both these scenarios there is very minimal impact on producer prices.

With the same price shock applied to both domestic production and imports, the sheep sector adjusts trade balance before domestic production. Imports fall and domestic production has negligible change. If the emissions intensity of imports were the same as the emissions intensity of UK sheep production, this would equate to a drop in global emissions equivalent to ~10% of current GHG emissions from UK sheep production. UKAMM estimates an overall drop in sheep consumption in the UK when a £50 per tonne carbon tax is applied both at the border and domestically, driven by a 7.5% increase in producer prices.

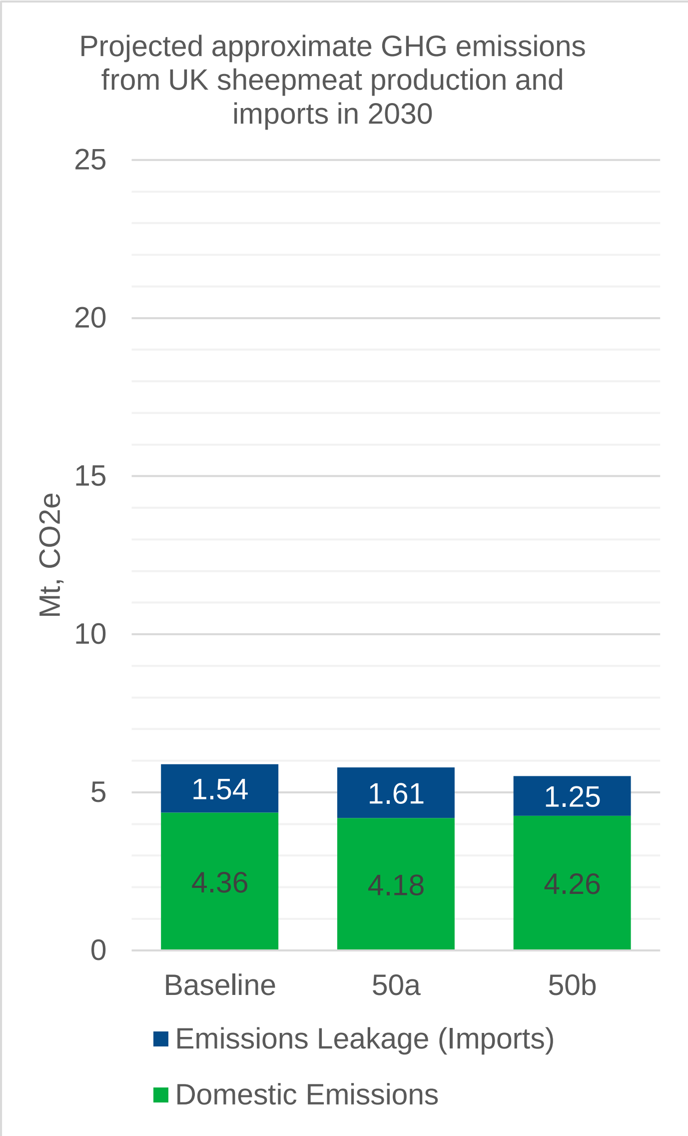

Figure 5 Projected approximate GHG emissions from UK sheepmeat production and imports in 2030 under baseline UKAMM projections, a domestic carbon tax of £50/tCO2e (50a) and an additional equivalent carbon tax on imports (50b).

Pork and poultry

Very minimal impact is observed in either sector, reflecting the low carbon intensity of these sectors relatively to cattle and sheep.

Milk

Small declines in production and territorial emissions observed. Fresh milk international trade is negligible, so no carbon leakage can be directly attributed to milk, but increases in the price of milk of 5% in response to a £50 per tonne domestic carbon tax contribute to the decline in production of dairy products like cheese and associated carbon leakage.

In the scenarios where carbon taxes are applied on imports as well as domestic production, there is a smaller decline in the production of dairy products as imports are less competitive with the carbon tariff - leading to a smaller decline in milk production for manufacturing. There is negligible difference in the UK's overall contribution to global emissions from milk utilisation between the 'a' and 'b' scenarios.

Figure 6 shows the difference between the annual figure for 2030 in the intervention scenario in question and in our baseline scenario.

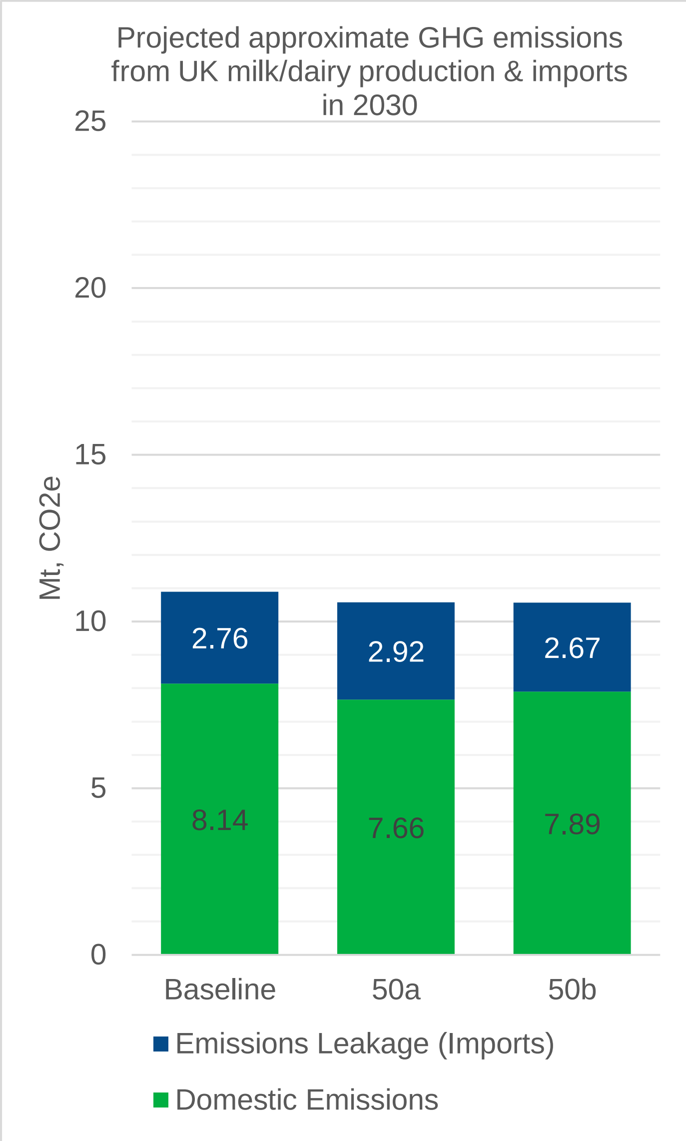

Figure 6 Projected approximate GHG emissions from UK milk production and dairy product mports in 2030 under baseline UKAMM projections, a domestic carbon tax of £50/tCO2e (50a) and an additional equivalent carbon tax on imports (50b).

Note that the emissions from imports are the emissions implied by the associated amount of milk used for the manufacture of the UK's four main dairy imports: cheese, butter, skimmed milk powder and whole milk powder.

Cheese

Small declines in production and territorial emissions made up for by carbon leakage in the 'a' scenario where carbon taxes are applied on domestic production only. Although this decline in production is prompted by an increase in the price of the key ingredient, milk, UKAMM simulates negligible change in cheese producer prices is

In the 'b' scenario where carbon taxes are applied on imports as well as domestic production, there is a smaller fall in production and territorial emissions than in the 'a' scenario but carbon leakage is eliminated.

Figure 7 shows the difference between the annual figure for 2030 in the intervention scenario in question and in our baseline scenario. Note that the only emissions attributed to cheese in this work are those produced by the necessary input of milk. Any emissions in the cheese manufacturing process are not accounted for.

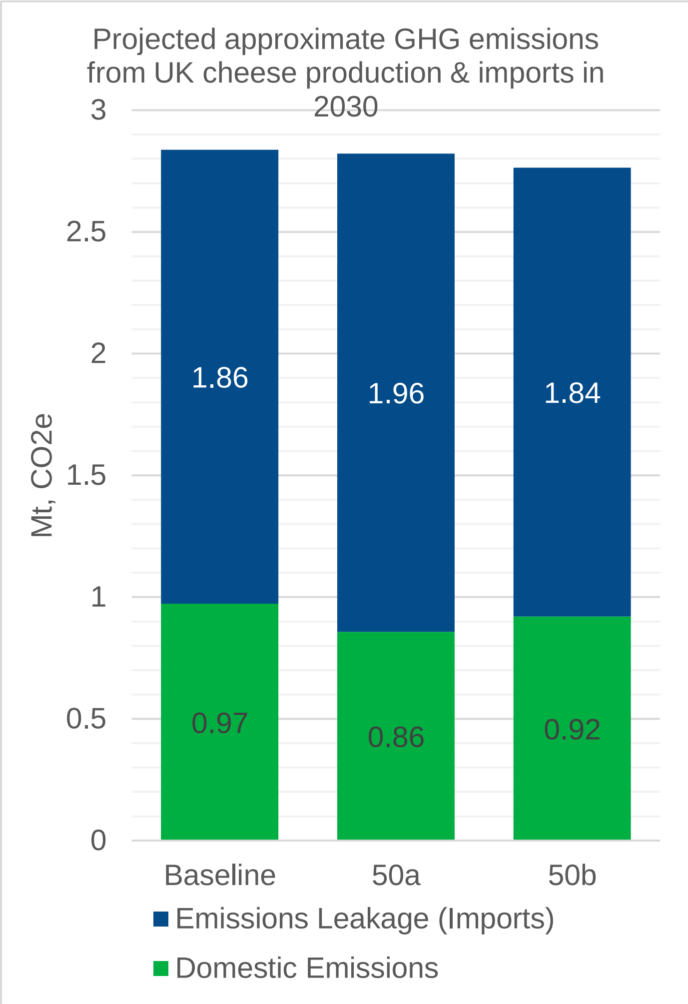

Figure 7 Projected approximate GHG emissions from UK cheese production and imports in 2030 under baseline UKAMM projections, a domestic carbon tax of £50/tCO2e (50a) and an additional equivalent carbon tax on imports (50b).

Carbon tax conclusions

Broadly, this modelling estimates that a carbon border tariff could limit the carbon leakage risk from a production-side carbon tax policy. In our model, the tax at the border prevents the price gap between domestically carbon taxed production incentivising a switch to imported products. Instead it forces consumer to face higher prices and make some consumption adjustment. It also prompts a significant fall in exports as UK prices rises and UK products becomes less competitive on the world market.

This scenario modelling also highlighted a risk that while carbon border policies might make climate mitigation policy more effective at reducing global emissions, in parallel they may reduce the impact of policies on territorial emissions. In the scenarios we modelled, domestic carbon taxes with no border policies had a significant impact on UK territorial emissions but after accounting for carbon leakage had a negligible overall impact on global greenhouse gas emissions. When a carbon border tariff was applied in parallel with the domestic carbon tax, UK territorial greenhouse gas emissions only decreased by half as much, but the carbon leakage effect was eliminated, meaning the policy's contribution to reducing global greenhouse gas emissions was unambiguous. This finding highlights a moral hazard to policy design: governments could have an incentive to pursue policies that foster carbon leakage as a way of meeting the Climate Change Act target, which apply only to UK territorial emissions.

Our findings could have been substantially different had our model been able to account for substitution to lower carbon production methods or lower carbon commodities (such as non-animal proteins), two mechanisms through which carbon border adjustment mechanisms are purported to bring about change over and above domestic carbon taxes alone. Carbon auditing that enables innovators to be charged lower carbon taxes and laggards to be charged higher carbon taxes could be an important facilitator of improvements to carbon intensity of production methods. In our model producers and consumers are assumed to be just as likely to forgo production or consumption in response to price rises as they have been historically[5] when these alternatives have been unavailable and carbon taxes are levied at a rate relative to sector average carbon intensity. Carbon border adjustment policies without accompanying policies to promote the transition to alternative production systems and lower carbon consumption choices could thus be vulnerable to perverse political incentives to remove carbon border barriers and turn to carbon offshoring to deliver domestic decarbonisation.

4.2 Diet Change

Theory of consumption-driven change

Proponents of reducing meat and dairy consumption highlight the relatively high environmental impacts of these types of food. The Vegetarian Society (2021), for example, cites research by Scarborough et al (2014) claiming that "reducing the amount of animal-based products in the diet represents an achievable way for an individual to reduce their carbon footprint". This is based on an assessment of the greenhouse gas emissions embodied in the diets of a large sample of people with different diets. However there is a subtle difference between this analysis and the claim that "moving to a vegetarian diet" will save an equivalent amount of carbon emissions as the difference in carbon footprint. An individual may be able to reduce the greenhouse gas emissions directly attributable to their own consumption choices that way, but economic analysis is required to understand what impact the change in consumption choices has on the agricultural production system where the emissions are actually produced, and thus the impact on global emissions. If the agricultural production system is not adjusting, in effect one individual may be reducing their carbon footprint by reducing their meat consumption only for it to increase the carbon footprint attributable to others. UKAMM helps us to question the extent to which agricultural

[5] Specifically, consumers' elasticities of demand are drawn from Tiffin et al, 2011.

production volumes adjust and the potential for reducing meat consumption to reduce overall greenhouse gas emissions from agriculture.

Diet change scenarios

We simulate changes in per capita consumption relative to its level in 2020 simultaneously for poultrymeat, pigmeat, beef, sheepmeat, cheese and milk. Our analysis works to four primary consumption scenarios designed to be in productive dialogue with existing analysis from the Climate Change Committee and others. They do not reflect current or projected trends in UK meat and dairy consumption. We set per capita consumption in 2030 to a proportion of what it is in 2020 and set per capita consumption in each year in between to a linear trend gradually approaching these four alternative 2030 levels:

- 10% reduction in meat and dairy consumption
- 20% reduction in meat and dairy consumption
- 35% reduction in meat and dairy consumption
- 50% reduction in meat and dairy consumption

Take beef as an example: in 2020, we expect each person to haven eaten about 16.8kg of beef[6]. We simulate what happens if that level is reduced, by 2030, to 15.1 kg (10% lower), 13.4kg (20% lower), 10.9kg (35% lower) and 8.4kg (50% lower). Each year in between is set to an incremental reduction. For the 10% reduction by 2030 scenario, for example, per capita consumption is reduced by 1% in 2021, 2% in 2022, 3% in 2023 and so on until it is reduced by 10% in 2030. We apply such reductions to all of the commodities of interest simultaneously and compare their impact on the agricultural market against what we would otherwise expect to happen – our baseline projections. These projections set out what we expect to happen if consumption patterns are left to adjust over time with incomes and prices as they would without intervention or change in consumer preferences. We make no explicit assumption about what may drive these changes in consumer behaviour.

[6] 2020 statistics had not yet been published at the time of writing, so these figures are UKAMM projections.

Table 4: Per Capita Consumption volumes by scenario

Per Capita Consumption: Scenarios and Levels						
Commodity	**2020**	**Baseline in 2030**	**10% by 2030**	**20% by 2030**	**35% by 2030**	**50% by 2030**
	Per capita consumption in 2020 – the reference year for all scenarios	Meat and dairy consumption follow current medium term trends.	Gradual reduction in meat and dairy consumption, reaching a 10% per capita fall in 2030 relative to 2020 levels.	Gradual reduction in meat and dairy consumption, reaching a 20% per capita fall in 2030 relative to 2020 levels.	Gradual reduction in meat and dairy consumption, reaching a 35% per capita fall in 2030 relative to 2020 levels.	Gradual reduction in meat and dairy consumption, reaching a 50% per capita fall in 2030 relative to 2020 levels.
Beef (kg)	16.8	17.2	15.11	13.43	10.91	8.4
Poultrymeat (kg)	31.1	34.7	28.0	24.9	20.2	15.5
Pigmeat (kg)	20.8	21.7	18.7	16.7	13.5	10.4
Sheepmeat (kg)	4.5	4.6	4.0	3.6	2.9	2.2
Cheese (kg)	11.8	12.4	10.6	9.4	7.7	5.9
Milk (litres)	111	102	91	81	66	51

Production Volumes

Our modelling suggests changes in consumption demand could have a relatively muted impact on production, if the UK agricultural economy continues functioning as it has done in recent years.

Were consumers to move away from meat and dairy, our simulation sees production falling for most meat and dairy products but to a very limited extent. In the simulation, falling demand in the UK does put downward pressure on prices and leads to a small decrease on production by farmers and processors. The exception is cheese production, which is projected to increase despite UK cheese consumption falling. Milk is the main input to making cheese, so as milk consumption declines and milk prices fall, cheese production costs are projected to fall by more than cheese prices. Cheese becomes more profitable and thus cheese production rises, despite consumption falling.

Our modelling foresees that the meat production decline is very significantly tampered by the role of international trade. The UK is a net importer of the four meat commodities studied as well as cheese. If UK consumer demand falls, a response is likely to be seen in reduced imports from abroad before reduced production domestically. This is because historically the domestic sector has been less responsive to changes in prices whereas imports adjust much more quickly. It takes time for animals to mature to slaughter age and this means there is a lag between farmers' decision making around production volumes and market conditions. If, in the short term, farmers have an option to switch markets they can do so more quickly than they can profitably reduce production.

As reflected in the modelling results, market-oriented livestock sectors with animals with shorter lifecycles such as poultry more readily adapt production to changes in consumption. This effect is realised through prices. As UK prices fall relative to prices overseas, UK consumers import less from overseas and in time UK producers export more as their goods become relatively more competitively priced.

Even in the medium-term UK production is relatively unresponsive to prices. Farmers often see their work as a vocation or even identity first and as a profit-making venture second. This means farmers keep producing to meet overseas demand even when they receive lower prices for their goods.

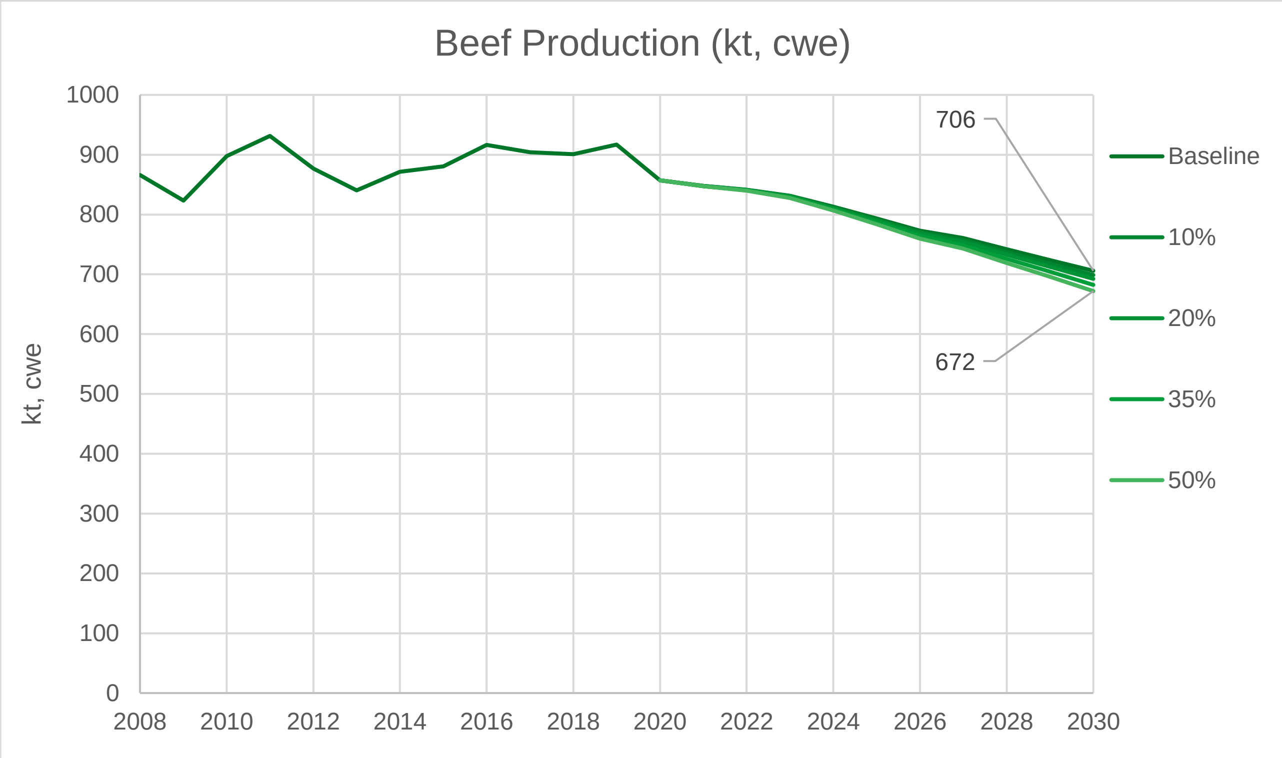

Figure 8 Projected UK beef production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

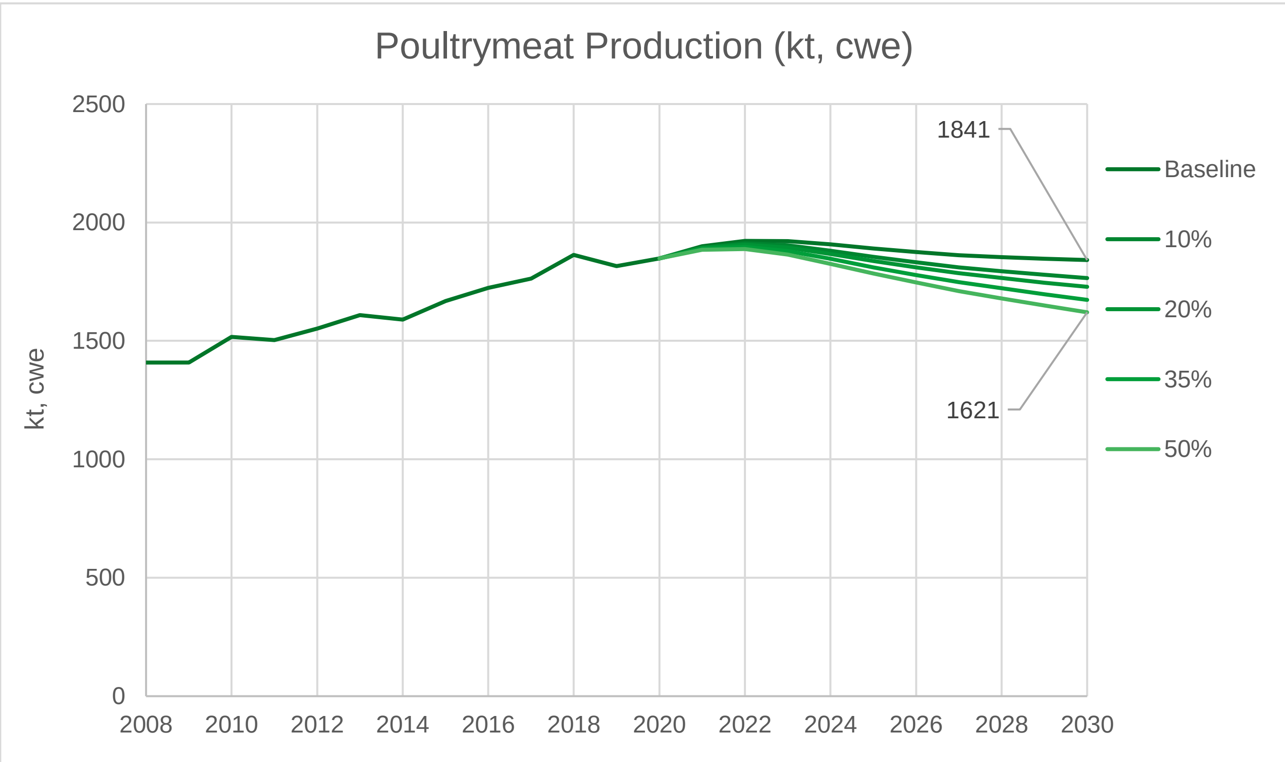

Figure 9 Projected UK poultrymeat production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

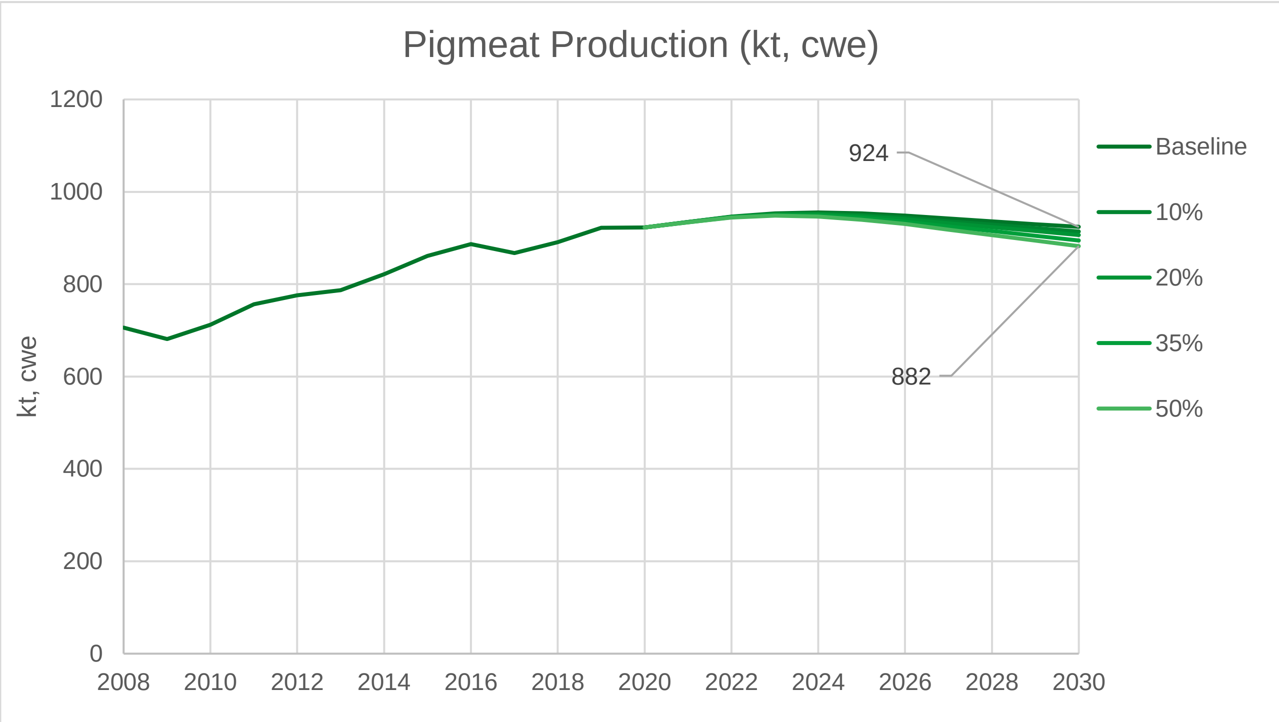

Figure 10 Projected UK pigmeat production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

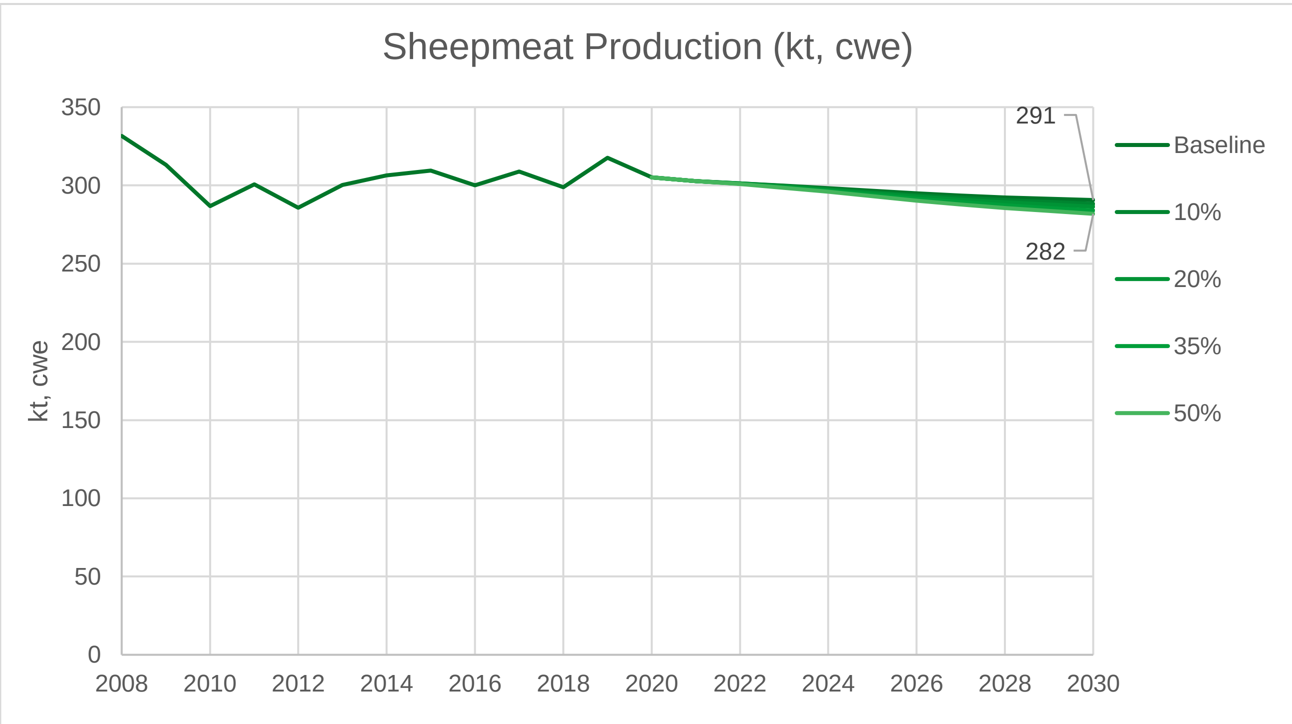

Figure 11 Projected UK sheepmeat production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

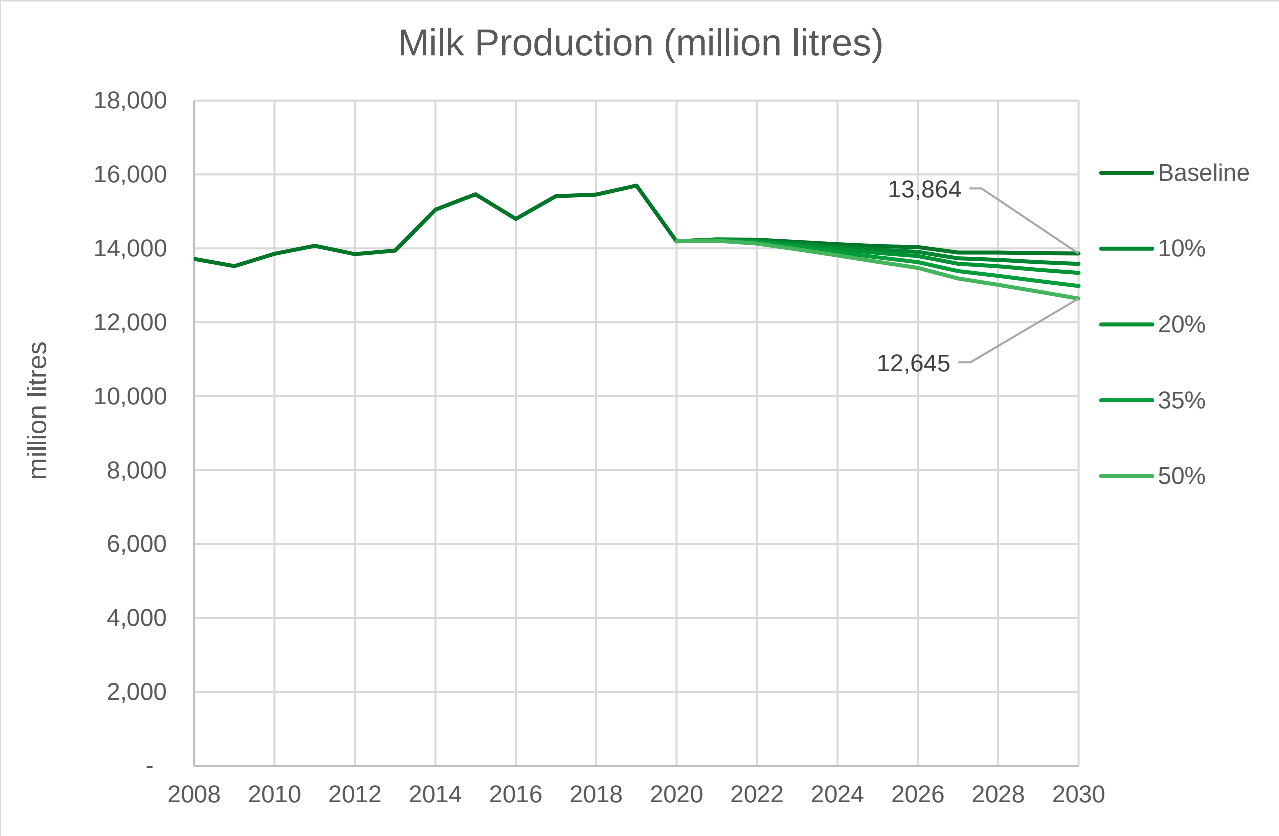

Figure 12 Projected UK milk production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

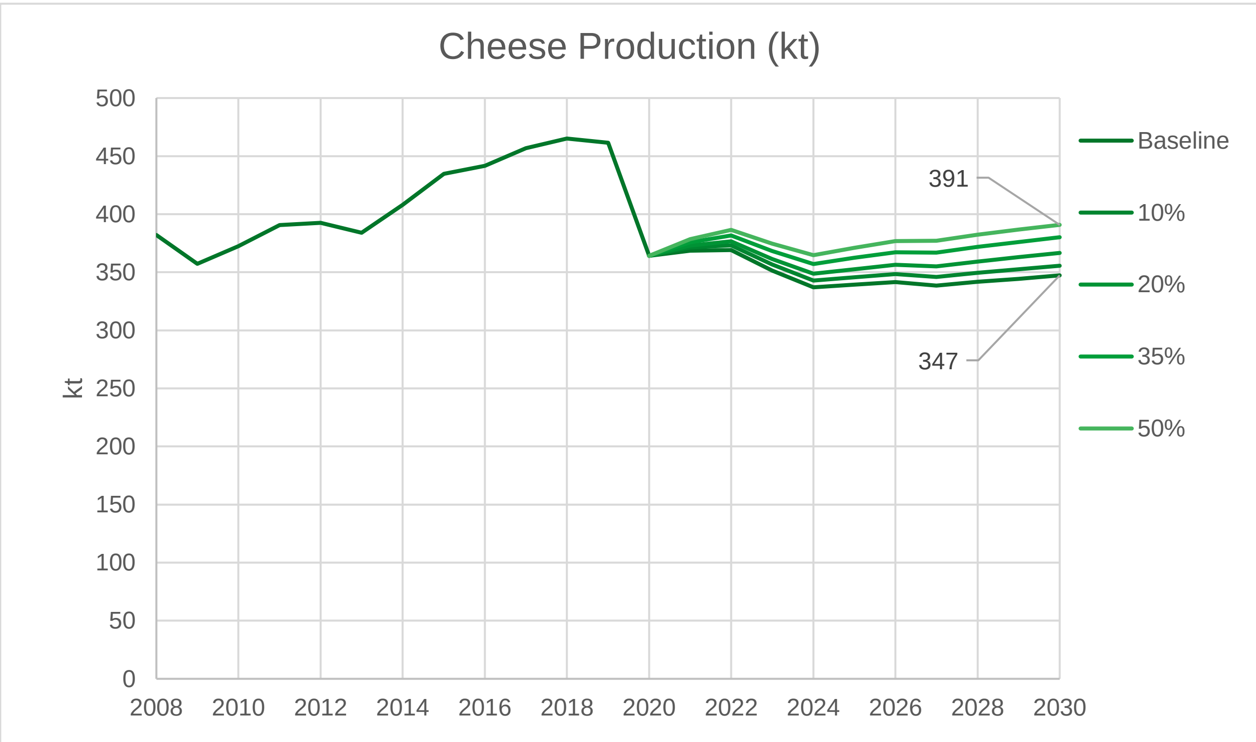

Figure 13 Projected UK cheese production over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

Table 5: Production volumes in 2030 under four scenarios for reduction in UK meat and dairy consumption demand. Percentage difference from baseline projections for 2030.

Commodity	10% Scen.	20% Scen.	35% Scen.	50% Scen.
Beef production in 2030 [kt, cwe]	-1%	-2%	-3%	-5%
Sheepmeat production in 2030 [kt, cwe]	-1%	-1%	-2%	-3%
Pigmeat production in 2030 [kt, cwe]	-1%	-2%	-3%	-4%
Poultrymeat production in 2030 [kt, cwe]	-4%	-6%	-9%	-12%
Cheese production in 2030 [kt]	+2%	+6%	+8%	+13%
Milk production in 2030 [million litres]	-2%	-4%	-6%	-9%

Implications for herd sizes

From table 6 it can be seen that even when consumption is reduced by 50% the ruminant herd numbers hardly change by 2030 but poultry flocks do. This is due to the market-responsiveness of each sector as well as the different lifecycles. For instance, cattle producers have a long wait between breeding and slaughter and so herd sizes today are based on market conditions in past years. With many beef and sheep farmers making a loss, there is also a question as to what extent they are motivated by prices. The recent history of the UK sheep industry illustrates this: from 1990-2019 sheepmeat consumption dropped by 35% and yet population only fell by 24%.

Poultry producers have 21 days until their eggs hatch and a further 8 weeks until they are ready for slaughter, allowing this much more market-driven segment to reduce flock counts quickly in response to market conditions.

Table 6: Herd sizes in 2030 under four scenarios for reduction in UK meat and dairy consumption demand. Percentage difference from baseline projections for 2030.

Herd size change in 2030 relative to baseline in each diet scenario	10% Scen.	20% Scen.	35% Scen.	50% Scen.
Cattle	-2%	-3%	-5%	-7%
Sheep	-1%	-2%	-3%	-3%
Pigs	-1%	-2%	-3%	-4%
Poultry	-4%	-6%	-9%	-12%

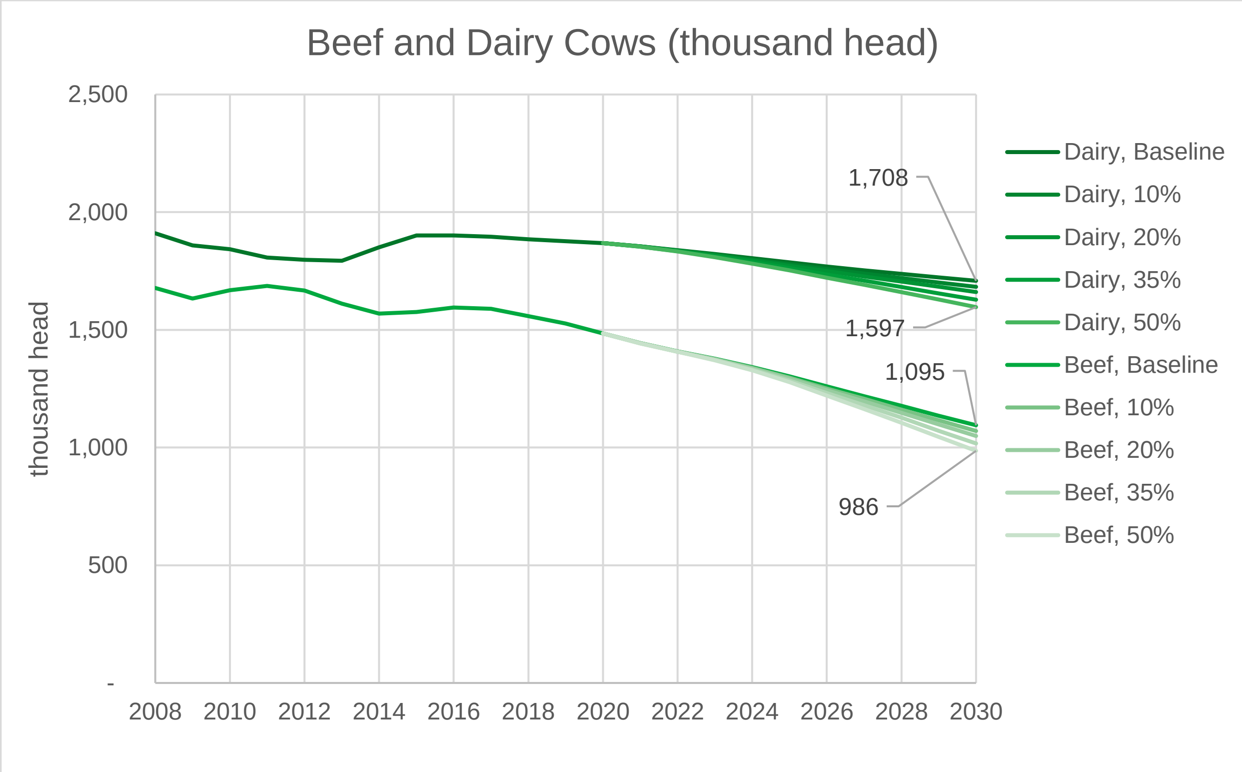

Figure 14 Projected UK beef and dairy cow herd over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

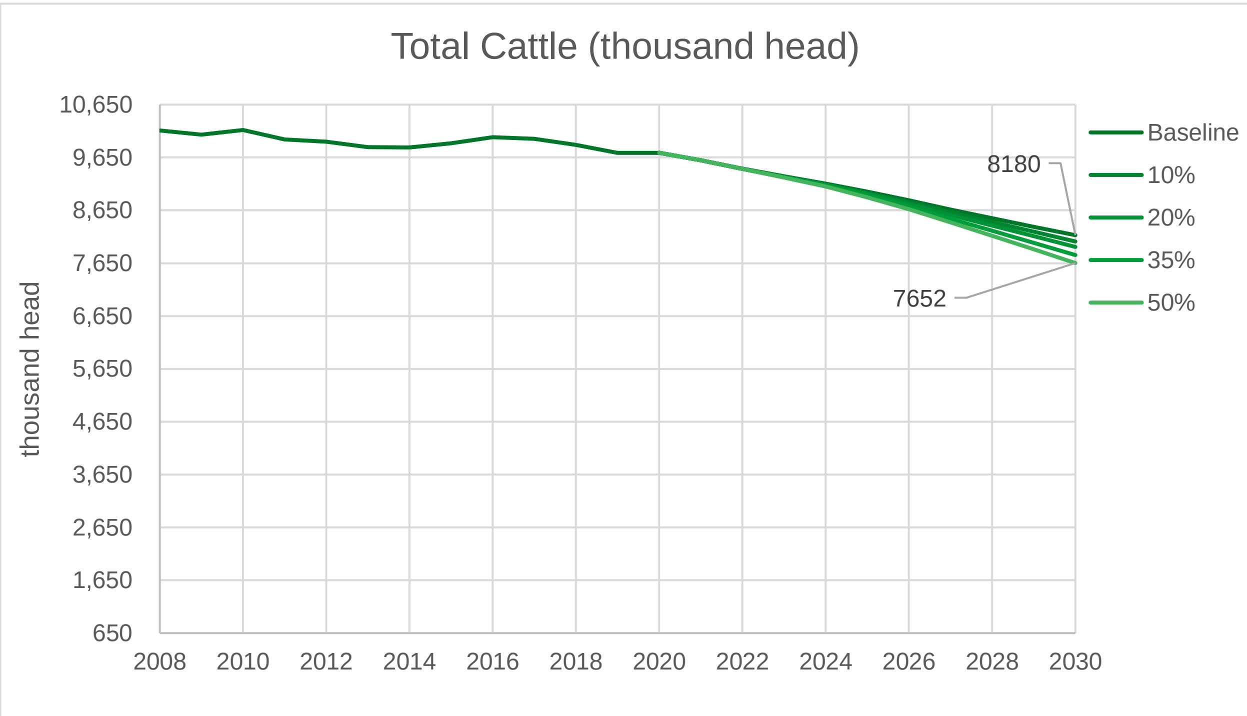

Figure 15 Projected UK total cattle herd (including cows, bulls and young cattle) over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

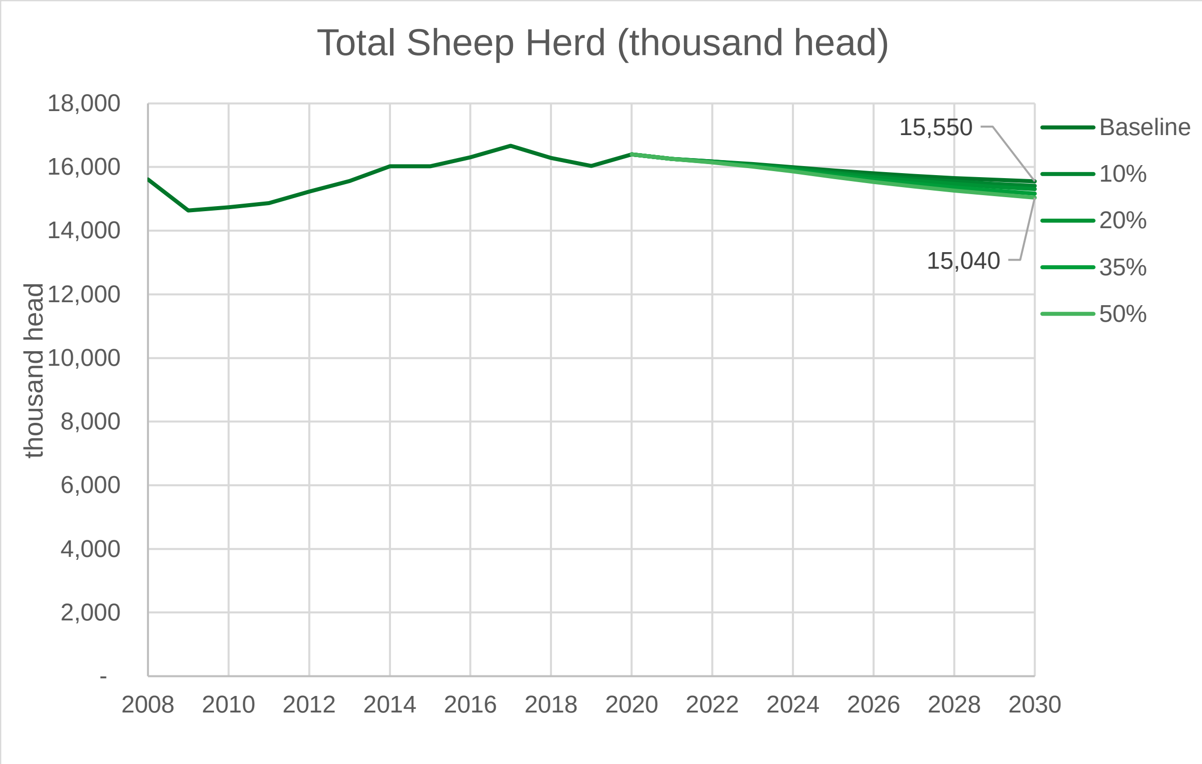

Figure 16 Projected UK sheep herd over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

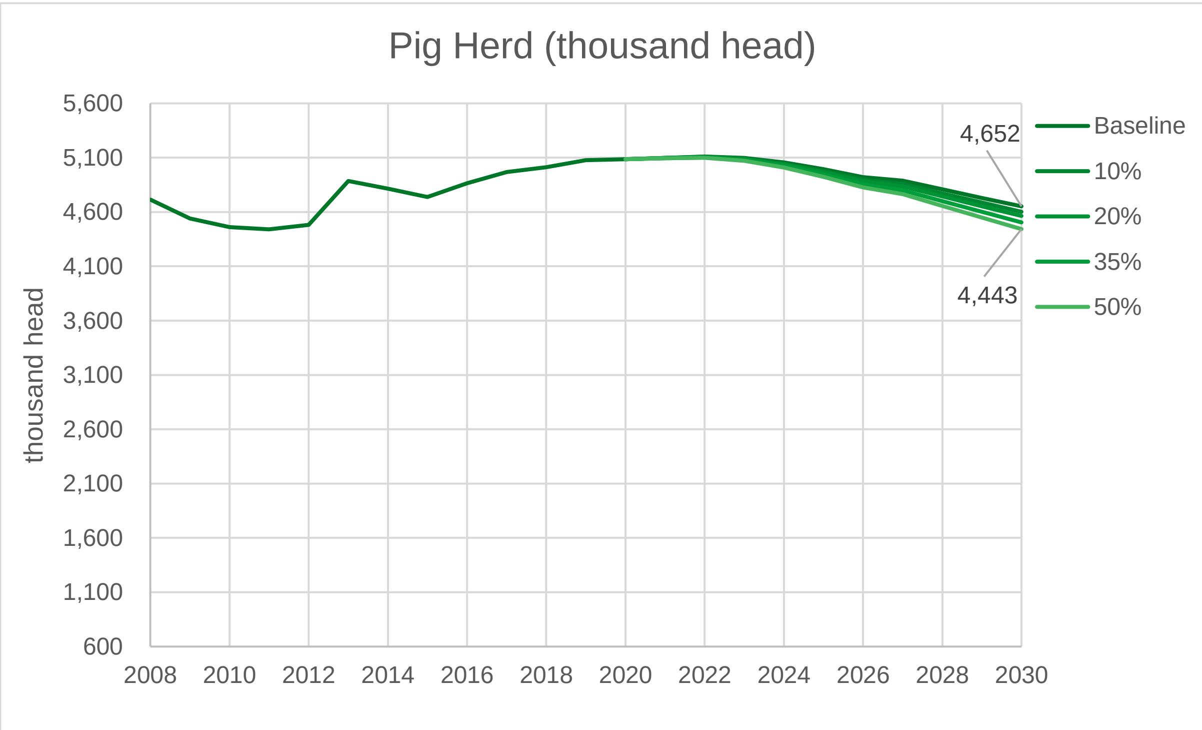

Figure 17 Projected UK pig herd over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

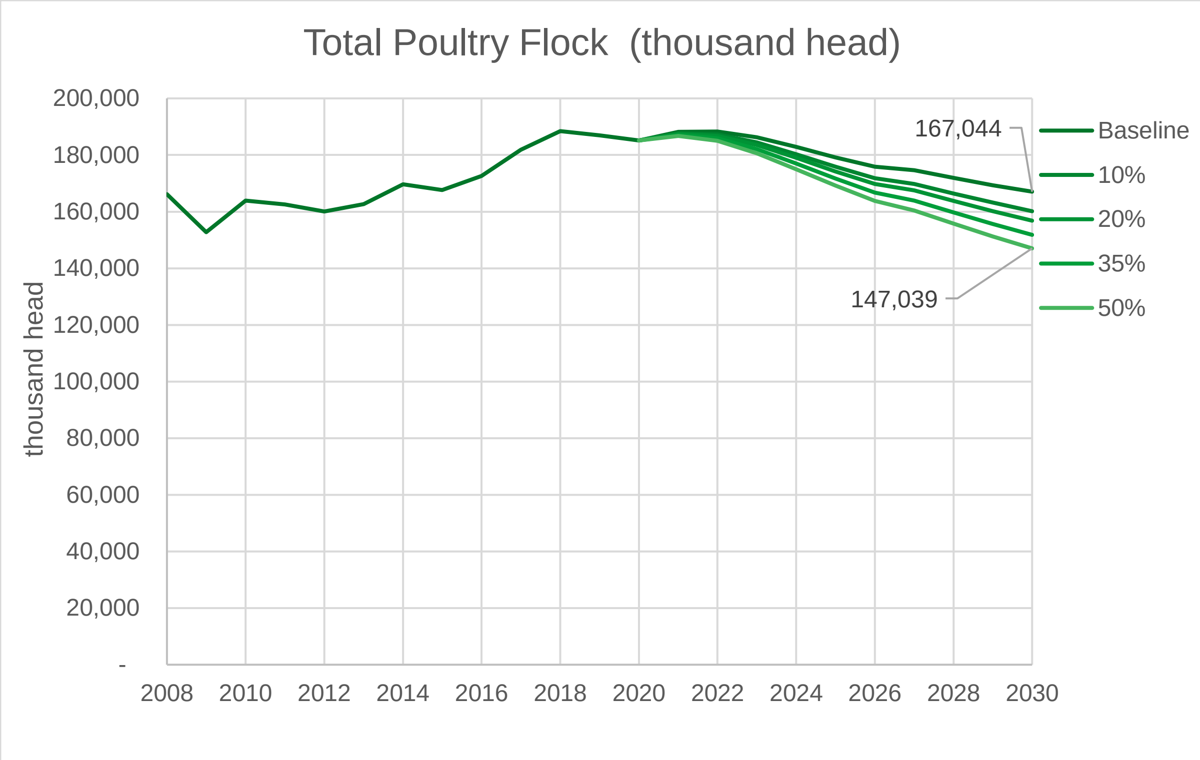

Figure 18 Projected UK total poultry flock (including table and laying hens, as well as other poultry such as turkeys and geese) over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

Trade matters

Trade plays a significant role in disconnecting changes in consumer diets from responses of UK producers. Although the UK is a net importer of meat and cheese, its exports are nonetheless significant, and they are projected to become more important if consumers reduce their demand for these commodities. When market prices fall in response to lower domestic demand, home produce becomes more competitive in international markets. We make no assumptions in this modelling about changes to diets in other countries, and so when our model projects that UK prices fall, it also projects that UK exports increase. This effect further supports UK production volumes despite falling consumption. As a net importer, concerns are often raised about the UK ‘carbon offshoring’ emissions to exporter countries. In this case the risk is of carbon on-shoring, whereby the UK supplies more of other countries’ meat commodities and therefore takes on other countries’ carbon footprint. To avoid emissions being simply shifting around the globe, solutions need either global co-ordination or careful consideration of complementary trade policy measures.

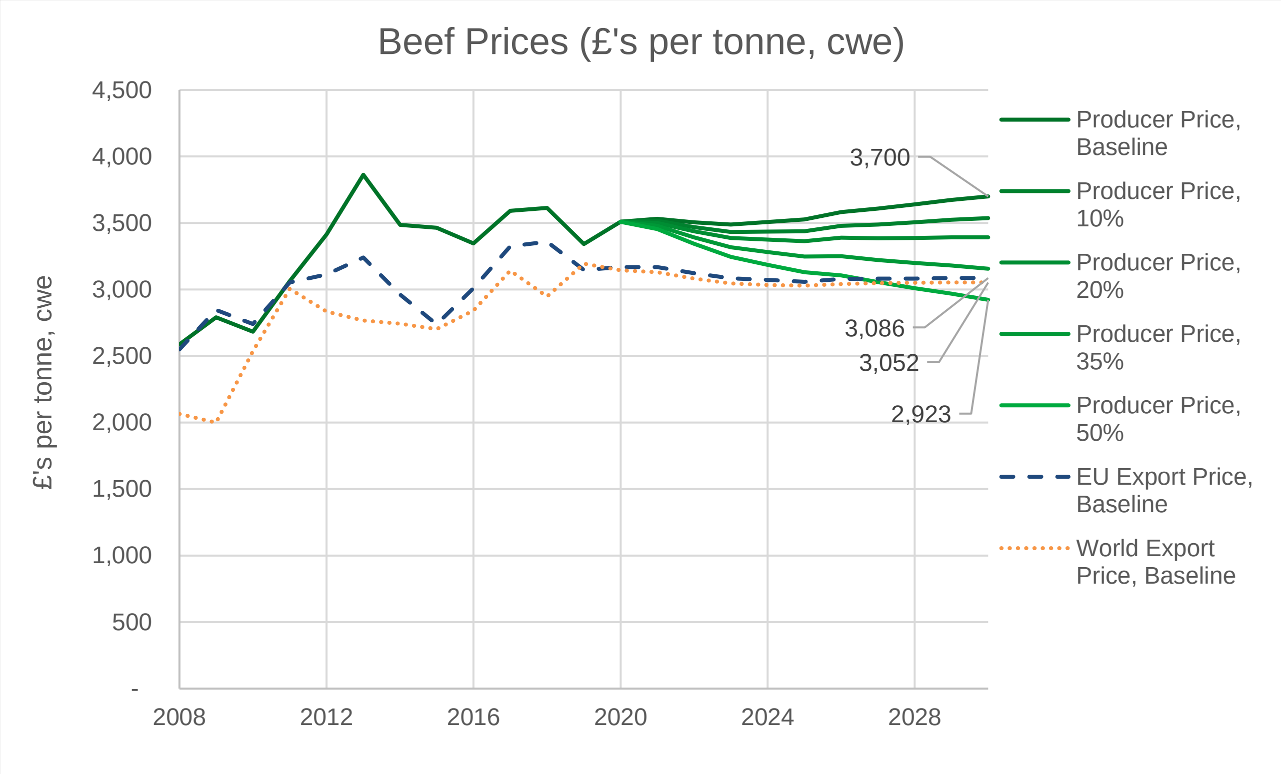

Figure 19 Projected beef prices in the UK, EU and rest-of-world markets over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

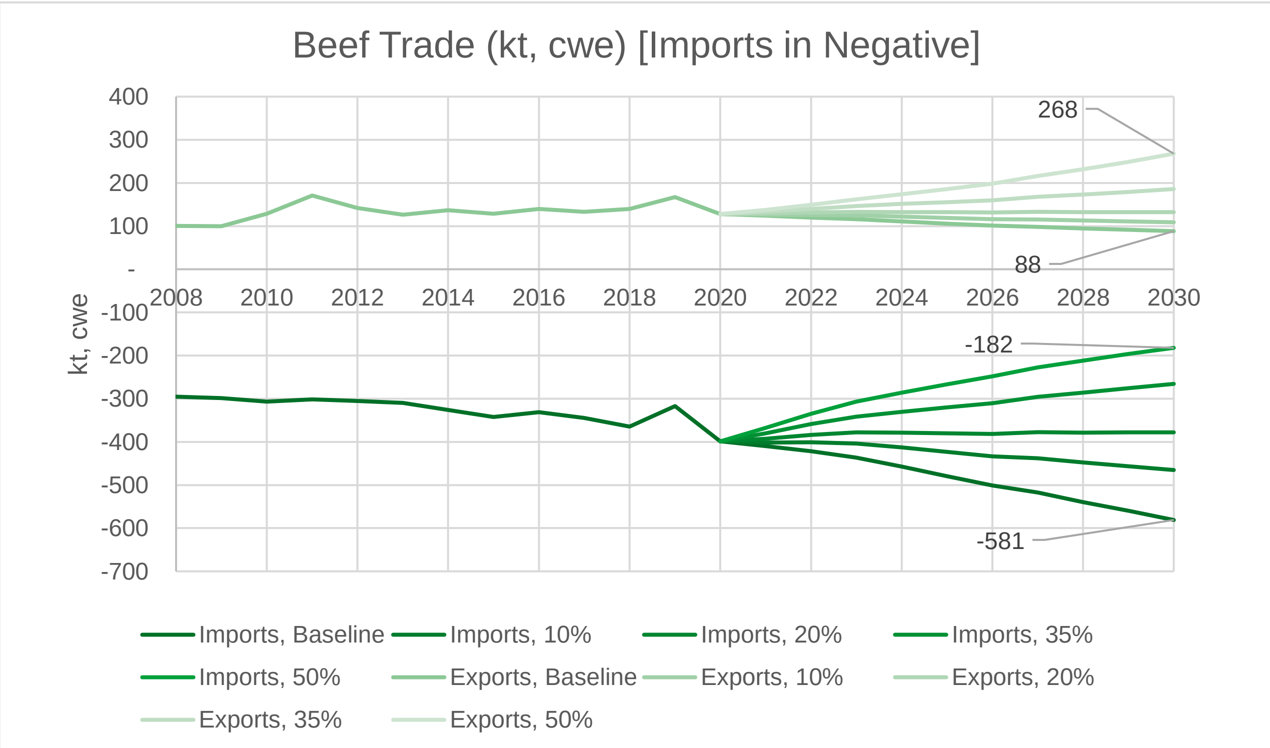

Figure 20 Projected UK total beef imports and exports over time under baseline UKAMM projections and varying degrees of reduced meat and dairy consumption. Projections begin in 2021.

4.3 Diet change as a carbon leakage measure

Carbon taxes under changing diets

Our modelling found the potential for carbon savings by targeting a reduction in consumer demand for high carbon agricultural products – namely ruminant meat – undermined by inelastic producers exporting overseas. We then found the potential for carbon savings by targeting high carbon producers undermined by inelastic consumers importing from overseas. This begs the question of how these two types of measures would interact. Could? Could production-side policies to incentivise the green transition prevent producers switching to export markets instead of reducing production if domestic consumers reduce their demand for high carbon goods?

To investigate whether policies to reduce demand for high carbon products could prevent carbon leakage from production side carbon mitigation policies, we combined our diet change scenarios with our 'leaky' carbon tax scenarios in which a tax is levied on domestic production scenarios. For the sake of simplicity we will present the results for a £50/tonne carbon tax only.

Starting by examining a 10% reduction in meat and dairy consumption, UKAMM finds its impact on beef production relatively similar whether occurring in the context of a carbon tax or not. In both cases it has a very mildly negative effect on UK beef production. But when we move to examine the trade balance, the picture is very different.

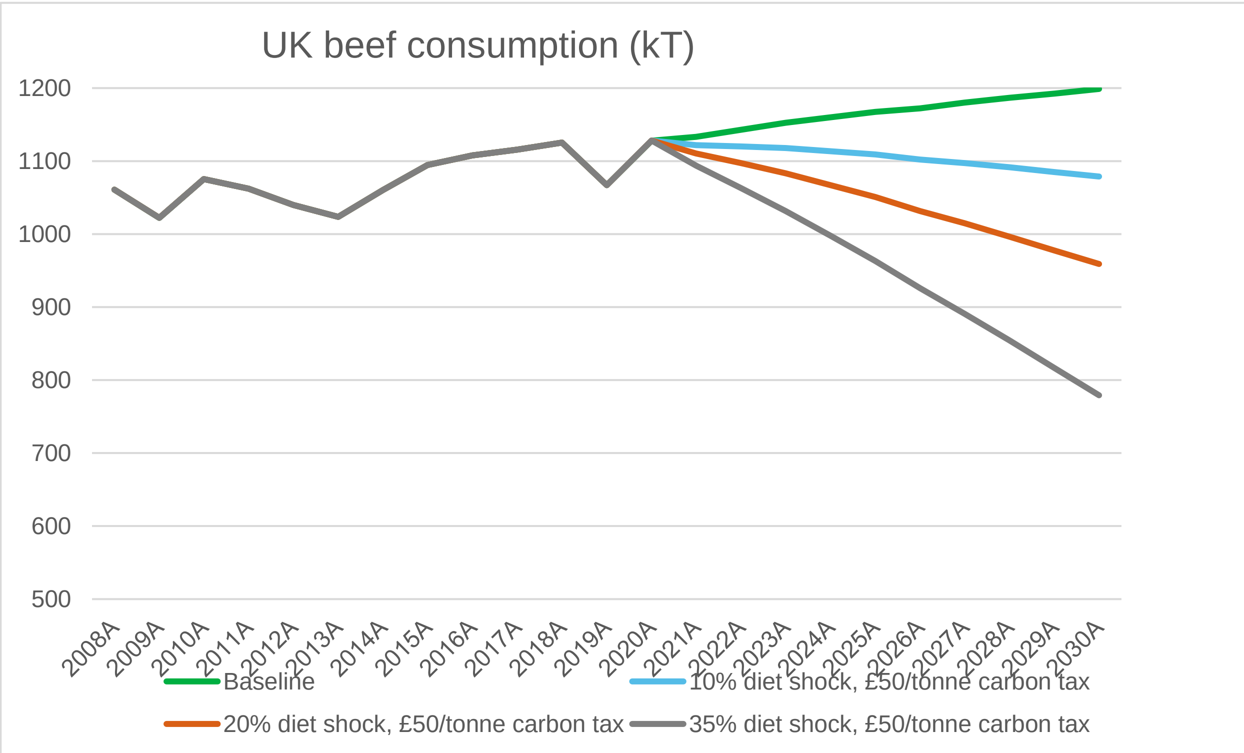

Figure 21 Projected UK beef consumption over time under baseline UKAMM projections and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

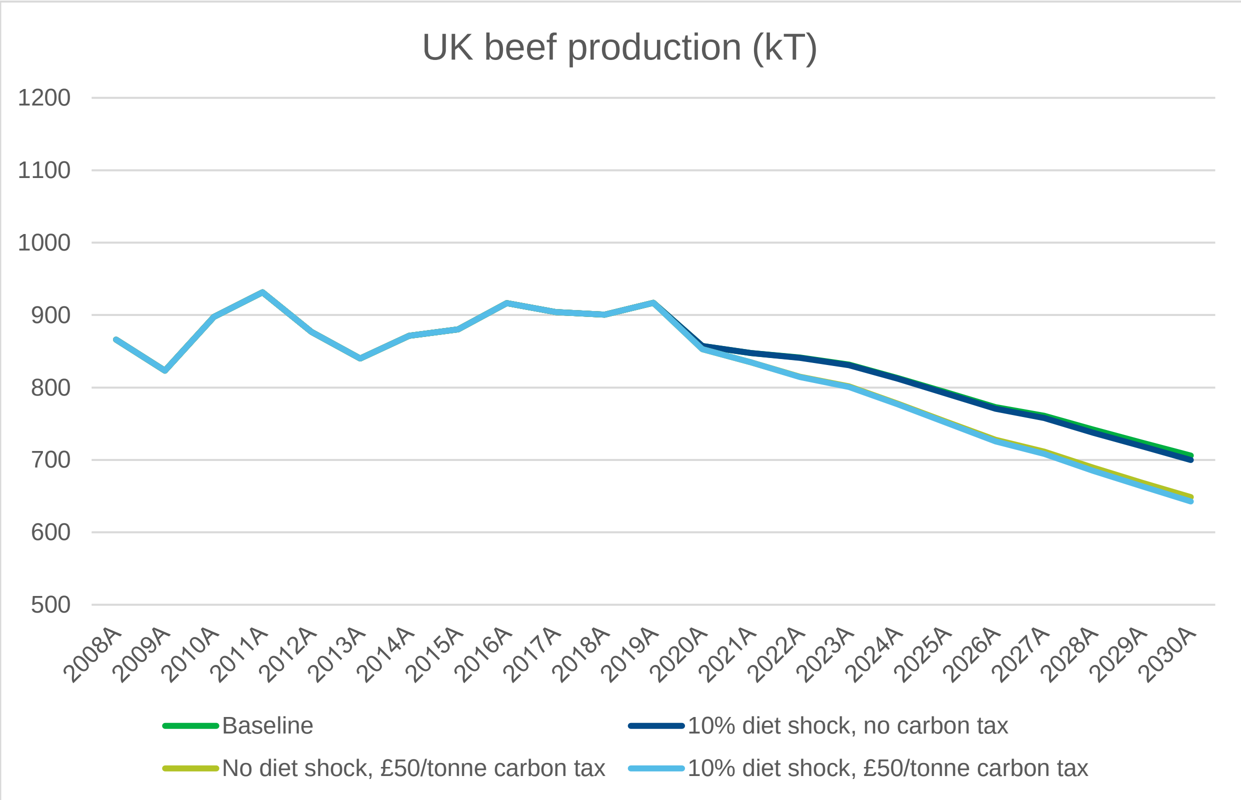

Figure 22 Projected UK beef production over time under baseline UKAMM projections and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

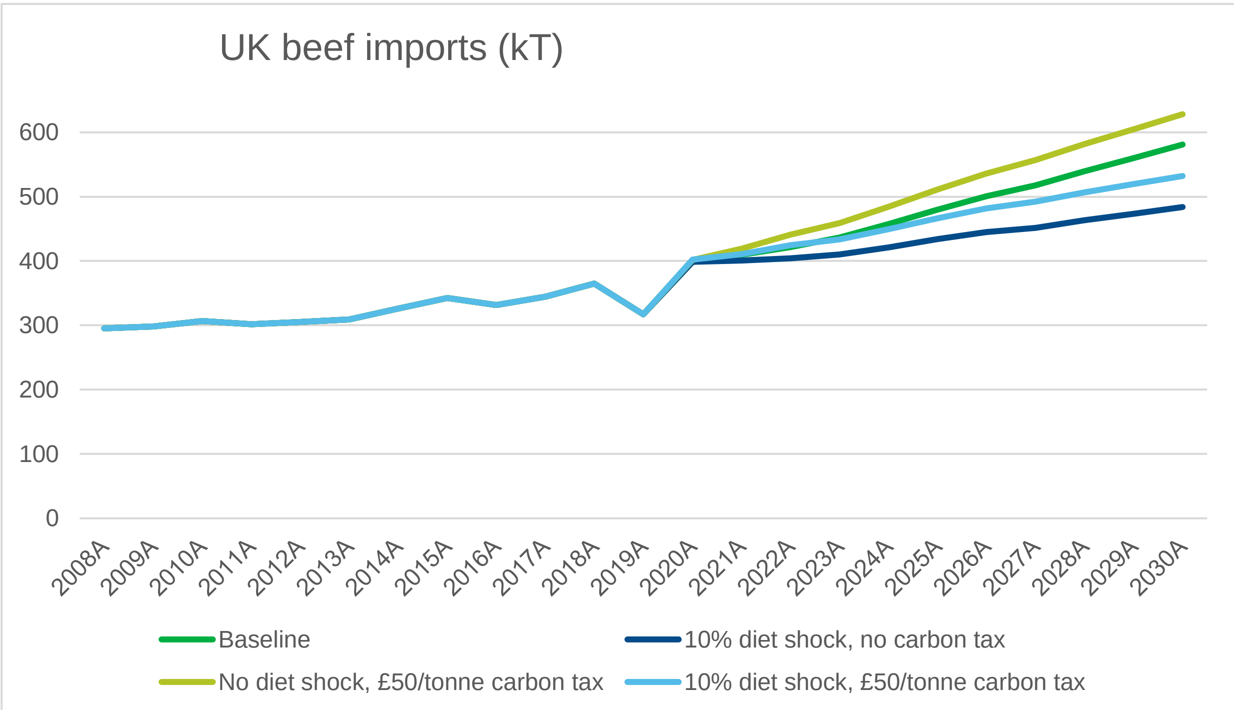

Figure 23 Projected UK beef imports over time under baseline UKAMM projections and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

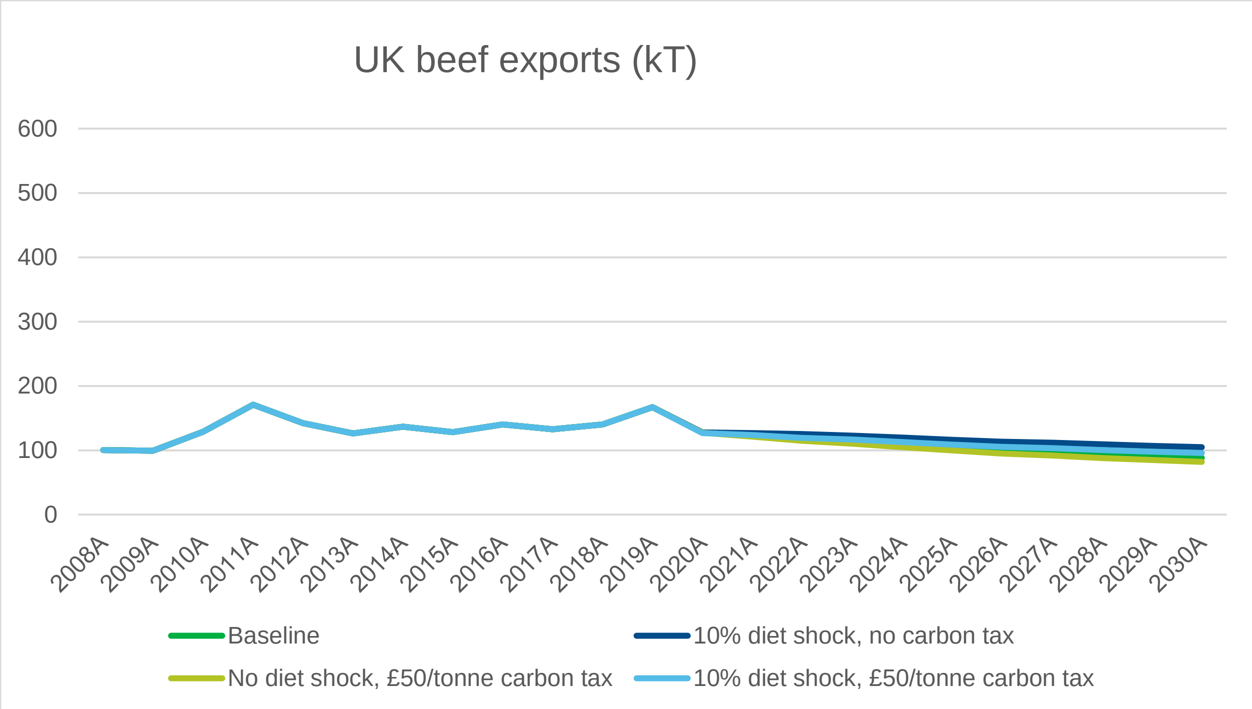

Figure 24 Projected UK beef exports over time under baseline UKAMM projections and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

The impact on UK beef imports is the most dramatic. When a £50 carbon tax is applied with no change in diets (light green line in figure 23), beef imports rise above the baseline level, demonstrating the carbon leakage effect. When meat consumption gradually reduces by 10% by 2030, the carbon leakage effect is reversed, with imports in fact reducing (illustrated by the light blue line in figure 23). Imports reduce further still if meat consumption falls by 10% without any carbon tax being applied.

In part these results reflect that international trade is the most elastic part of UK agricultural markets. UK producers have not historically adjusted production quickly in response to market prices. UK consumers display a preference for UK produced goods and they adjust their consumption of imported goods in response to price changes more readily than they adjust their consumption of UK goods. This means that when there is no pressure on the production side from a carbon tax or other similar policies, consumers may first reduce their imported consumption. Even when there is a substantial £50/tonne production-side carbon tax raising prices, consumers reduce their imported consumption by more than they reduce their domestically produced consumption.

This modelling suggests that reductions in meat consumption could be an effective tool in preventing carbon leakage generated by domestic carbon taxation, in some ways an alternative to border carbon taxes. If climate mitigation makes domestic consumption more expensive, consumers' inelastic preferences means they are likely to substitute to imports rather than reduce consumption. If an exogenous means is found to shift consumer preferences and reduce meat demand, consumers may forego consumption altogether rather than substituting to imports.

If diet change occurs in parallel with both a domestic carbon tax and a border tax on carbon, UKAMM modelling foresees the largest decline in UK beef production of the scenarios studied. Without diet change, putting a carbon tax at the border could force UK consumers to face higher prices rather than switching to untaxed imports. We also project it to cause a diversion of exports to domestic consumption. With a 10% reduction in meat and dairy consumption in parallel with a £50 per tonne carbon tax on domestic production and at the border, the impact on imports is even greater, although less than the sum of the decline in imports in the separate diet shock and border carbon tax scenarios. Exports are still redirected to domestic consumption. There is a slight decline in imports, bigger than both the separate diet shock and border carbon tax scenarios but again smaller than their sum.

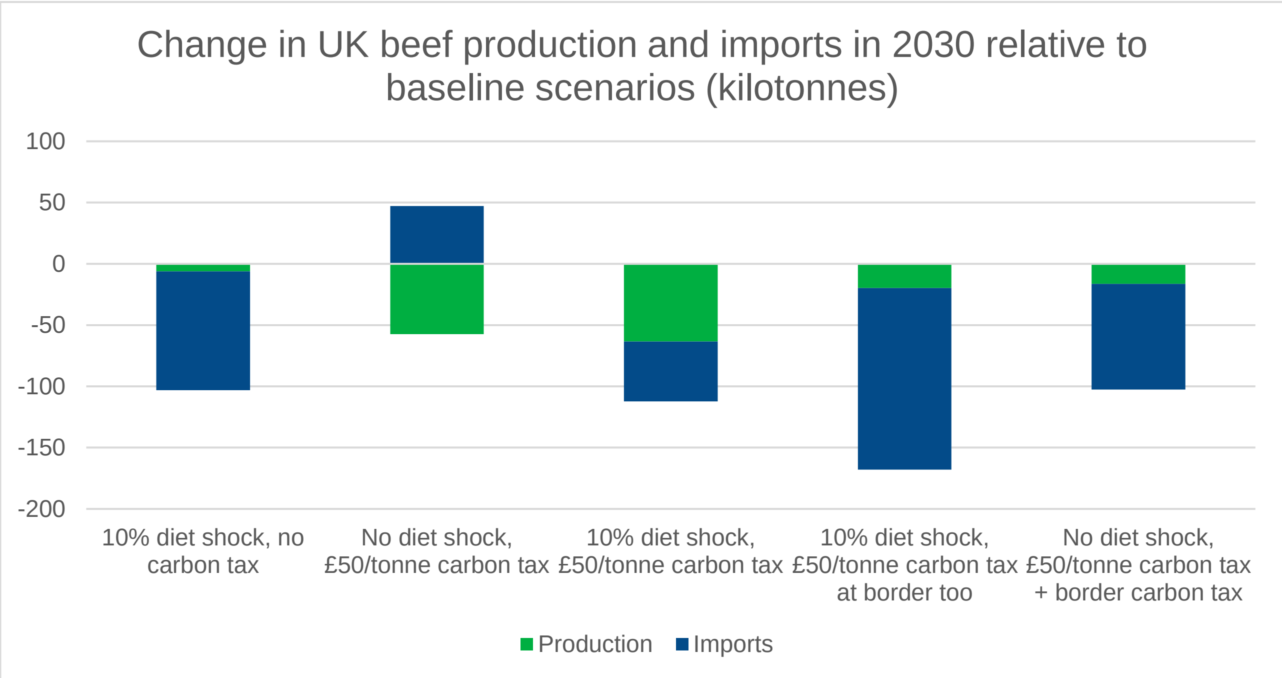

Figure 25 Projected change in UK beef production and imports from baseline UKAMM projections in 2030 and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

Comparing the absolute change in annual UK beef production and imports in 2030 with the baseline scenario, we see that the scenario in which there is a diet shock and a £50/tonne carbon tax both on domestic production and at the border has the greatest impact on overall UK beef utilisation. The scenario in which there is a diet shock and a carbon tax on domestic production only has the greatest impact on domestic production.

The impact on global emissions from beef production depends on the relative carbon intensity of beef production in the UK and in countries that export to the UK. The average carbon intensity of imports would have to be 56% lower than the carbon intensity of UK production for the scenario with a diet shock and a domestic carbon tax but without a carbon border tax to have a greater impact on global emissions than the scenario with diet shock and both a domestic and border carbon tax. The carbon intensity of imports would have to be 18% higher than UK production for a 10% reduction in meat and dairy consumption to have a greater impact on emissions from beef production than the same diet shock accompanied by the £50 per tonne carbon tax on domestic production only. The carbon intensity of imports would have to be 26% higher than UK production for a £50 per tonne carbon tax on both imports and domestic production with no change in diets to bring about a greater impact on global emissions from beef than a domestic carbon tax only accompanied by a 10% reduction in meat and dairy consumption.

Table 7: Summary of Scenario Results – Diet Change combined with Carbon Taxes

	No diet change	10% diet change
No carbon tax	Baseline	Large reduction in imports, small fall in production
Domestic carbon tax only	Medium rise in imports, medium fall in production	Medium fall in imports, medium fall in production
Domestic and border carbon tax	Large reduction in imports, small fall in production	Very large fall in imports, small fall in production

Price impacts

The effectiveness of the carbon border tax is delivered by a significant increase in producer prices. This is most extreme in the scenario with no diet shock, where beef prices are projected to rise by 22%, and only slight tapered by the 10% reduction in meat and dairy demand to a 19% price rise in that scenario. As would be expected, a simple fall in demand for meat and dairy consumption without any change in taxation gives rise to a fall in prices.

When a domestic carbon tax is levied alone, with no border tax and no change in diets, prices rise slightly but the substitution to untaxed imports prevents prices increasing by more than a couple of percent. When a 10% diet shock is applied in tandem with a £50 per tonne carbon tax on domestic production only, prices fall very slightly. Further modelling runs would be needed to establish how this would change with different scales of diet shock and different rates of carbon taxation.

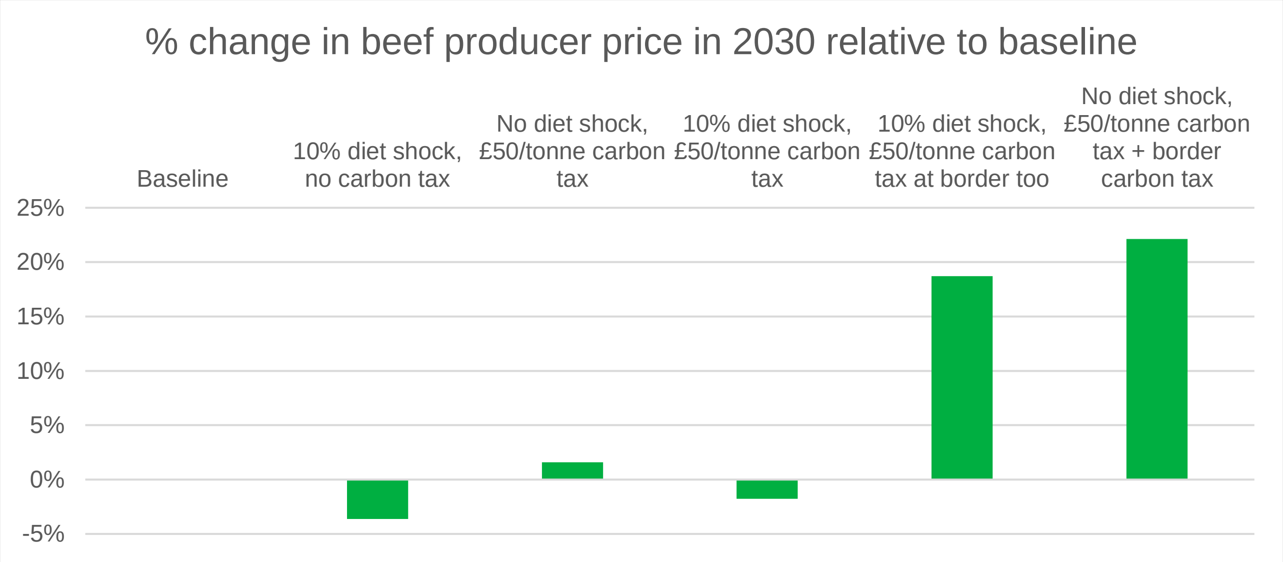

Figure 26 Projected change in UK beef prices from baseline UKAMM projections in 2030 and select combination scenarios of reduce meat and dairy consumption, domestic carbon taxes and carbon taxes on imports. Projections begin in 2021.

If carbon taxes incentivise carbon intensity improvements

No improvements in carbon intensity are modelled, despite this being a hypothesised outcome of the application of a carbon tax. Were these carbon intensity improvements to be realised, the carbon intensity of UK produced goods would be lower in carbon tax and carbon border tax scenarios than the baseline, and lower for overseas produced goods in carbon border tax scenarios than in both the baseline and domestic carbon tax scenarios. If carbon intensity were to improve, the emissions savings from lowering production would be smaller in absolute terms. The overall impact on emissions would be delivered not only from the reduction in production at home and overseas but by the reduction in emissions from the remaining part of domestic production.

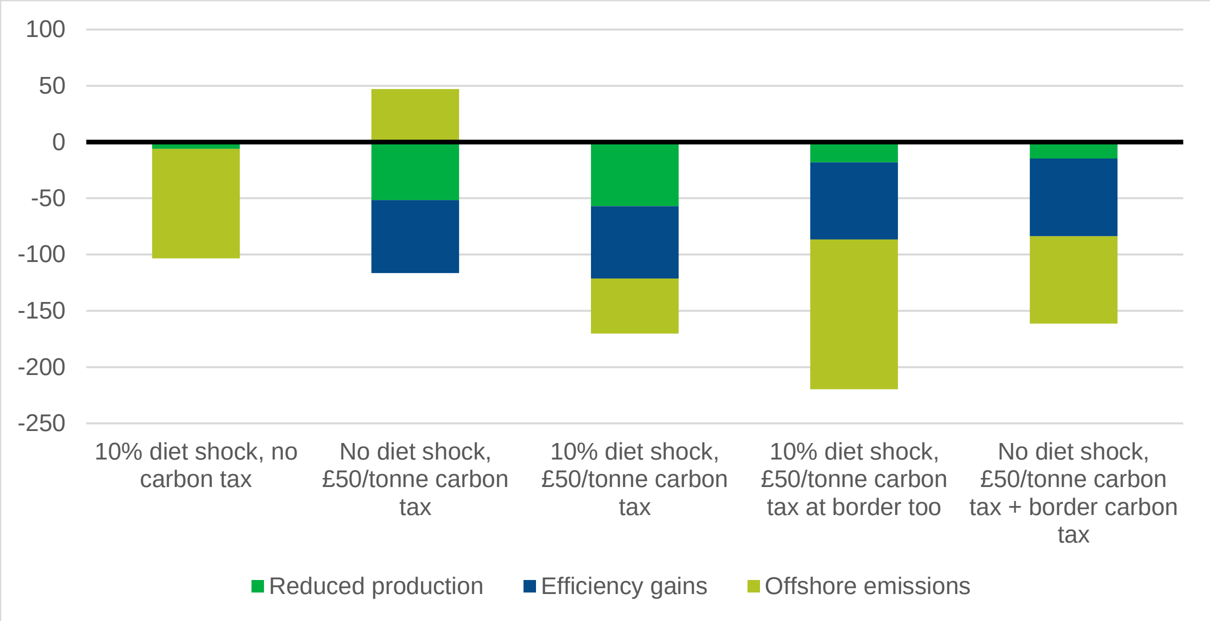

Figure 27 **:** Beef emissions changes if carbon taxes yield a 10% improvement in carbon intensity of home production and of imports, and if imported beef carbon intensity assumed the same as UK beef. (Indexed relative to current carbon intensity of UK beef production.)

Figure 27 shows an estimation of the relative impact of the various carbon tax and diet shocks on emissions if UK and overseas carbon intensities are assumed to be the same and if carbon taxes are assumed to improve carbon intensity by 10%. Efficiency gains of 10% from the part of domestic production unaffected by the reduction in production have a similar scale of effect on emissions as the emissions saved by reduced import demand across scenarios. This does not account for the fact that reducing carbon intensity will reduce the tax burden on farmers and potentially mitigate the push to reduce production. More complete modelling taking that into account may show slightly more modest reductions in UK production in the carbon tax scenarios and thus slightly more modest reductions in global beef emissions.

5. Conclusions

Our modelling highlights a powerful role for reductions in UK meat and dairy consumption in preventing carbon leakage as UK agriculture takes action to reduce its greenhouse gas emissions. Reducing consumer demand could be an alternative to measures like a carbon border tax that achieve similar outcomes at the cost of higher consumer prices. Further research is needed to understand what impact the reduction in UK demand for meat and dairy imports would have on the world markets and thus what contribution this would make to reducing global agricultural greenhouse gas emissions. Modelling of multilateral reductions in meat and dairy consumption find it leading to a significant reduction in global greenhouse gas emissions (OECD, 2019; Stehfest et al, 2009).l

Our modelling also highlights the nuance international trade analysis brings to the assessment of agri-climate policies. Our modelling does not find diet change to be an effective primary lever for herd size adjustment in the UK due to the role of international trade. With cattle and sheep responsible for the majority of greenhouse gas emissions from agriculture in the UK and around the world, herd size adjustment must be considered alongside productivity and carbon intensity measures in the agri-climate policy debate. At present many conversations about herd size reduction take place by proxy through diet change, which our analysis suggests may not deliver changes in herd size under current global animal products market conditions. We question whether conversations about herd size reduction might be better posed directly, as production than consumption questions, with full consideration of international trade.

Table 8: summary of scenarios studied for this report

Mitigation measure	Scenarios
Diets	10%, 20%, 25% and 50% reductions in meat and dairy consumption. Healthy eating variant.
Taxes	£15 or £50 per tonne CO2e. UK production only or at border too.

This analysis also highlights the moral hazard created by UK climate targets only applying to territorial emissions and not overseas emissions. A carbon tax on UK production alone and not on imports appears to do most to reduce UK territorial emissions, marginally more so when accompanied by a 10% reduction in meat and dairy consumption. Unless accompanied by change in diets, this is essentially a policy of deliberate offshoring of emissions as consumers substitute to imports. The best strategy to meet territorial emissions targets may not be the best strategy for reducing the share of global emissions attributable to UK consumption. Border carbon taxes could also create incentives for deliberate offshoring strategies if their impact on consumer prices proves unpalatable.

An area not considered here is the potential for carbon taxation to incentivise improvements in carbon intensity. A carbon pricing system that differentiates between high and low carbon firms, not simply based on an industry-average emissions intensity, could incentivise investment in efficiency measures and increase the market share of farms that implement mitigation measures. Farm carbon audits, as trialled in the Scottish Government's Farm Business Survey (Coakley, 2019), would be an essential part of that policy package.

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