Exploring the Implications of GHG Reduction Targets for Agriculture in the United Kingdom and Ireland

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Abstract

The UK and Ireland both have large greenhouse gas (GHG) reduction targets under the EU Effort Sharing Decision (ESD). The ESD covers non-emission trading sector (Non-ETS) emissions, of which agriculture is an important component, representing 44% of the non-ETS emissions for Ireland. In the UK this figure is lower, at 16%, but the composition varies significantly between the constituent countries. Though the reductions targets and means of achieving them differ, reductions in agricultural emissions will be necessary for both the UK and Ireland, and on-going negotiations setting reductions targets for 2030 are likely to result in even stricter limits for emissions from the non ETS sector. This paper examines the implications of achievement of possible 2020 and 2030 GHG reductions targets in the agriculture sector for the UK and Ireland. The paper considers the achievability of the reduction targets based on technical means alone, suggesting that under current carbon budgets the UK aims to make sufficient agricultural emissions reductions, while Ireland will require a reduction in agricultural activity or alternative policy interventions. The implications for food production in the UK and Ireland and associated trade are then assessed.

Keywords Climate change, agricultural production, agricultural trade

JEL code **Q100** Agriculture: General; **Q54** Global Warming

1. Introduction

International efforts to deal with climate change began with the Rio Earth Summit in 1992, which led to the adoption of the UN Framework Convention on Climate Change (UNFCCC). It set out a roadmap for action to stabilise the atmospheric concentration of greenhouse gas emissions (GHGs) in order to limit the effect of man-made GHGs on the climate.

The international response to climate change has received extensive media coverage of late, primarily due to the Conference of Parties (COP) held in Paris in December 2015. The main objective of COP21 was to establish a new global agreement to limit climate change. This agreement represents the UNFCCC's biggest achievements since COP3 resulted in the Kyoto Protocol in 1997.

Food production has increased dramatically over the last fifty years, in line with the increase in the world's human population. As a consequence, agriculture is a significant source of human induced global GHG emissions. Due to uncertainties, it is not possible to provide one single figure, but it is estimated that food-system emissions - from production to consumption - contribute from 9,800 million to 16,900 million metric tonnes of carbon-dioxide equivalent ($MtCO_2e$) per year, or nineteen to twenty-nine per cent of total GHG emissions. This encompasses emissions from agriculture and the production of associated inputs, as well as emissions from food processing, packaging and distribution (Vermeulen et al., 2012).

In a European context, research indicates that in the current century the projected temperature increases in the Mediterranean region in summer will be around 4°C, and the projected precipitation decreases will be up to fifty per cent, while the corresponding changes projected for the UK and Ireland are much smaller (IPCC, 2007; World Bank, 2012). If these projections are borne out, agriculture in the Mediterranean region will in the future face greater climatic challenges when compared to the UK and Ireland. This could call into question European Union (EU) policies whose effect would be to limit food production in regions of Europe that would be less susceptible to climate change. Therefore, in the context of European food security, environmental policies that adversely affect agricultural production in regions that are likely to be less adversely affected by climate change may prove controversial.

2. EU emissions reductions targets

The European Union has established two mechanisms to manage GHG emissions across the MS. The Emissions Trading System (ETS) is a pan EU cap and trade scheme covering over 11,000 factories and power stations. Under the ETS, emissions permits can trade across borders, with an overall emissions reduction target of 1.74% year, which would result in an overall reduction from 2005 ETS sector emissions of 21% in 2020. There are no individual MS ETS emission reduction targets, rather it is left to the market to determine the emissions reductions that are achieved in each MS.

Agricultural GHG emissions lie outside the ETS as part of the Non Emissions Trading (Non ETS) sector, along with transport, residential emissions, smaller industrial installations and waste. In both Ireland and the UK, the transport sector represents a large share of the emissions of the non ETS sector. Collectively the EU must deliver a Non ETS GHG emissions reduction of 10% by 2020. Under the Effort Sharing Decision (ESD) agreed in 2009 (Decision no 406/2009 of the European Parliament and the Council), each EU MS has been assigned a GHG emissions target for 2020, which represents a percentage change relative to the associated emissions level in 2005, as illustrated in Figure 1. The 2020 effort share allocated to each MS in the ESD is largely determined by MS GDP levels at the time the agreement was negotiated. Ireland is one of three Member States allocated the largest reduction target of 20%, while the reduction target for the UK is also substantial at 16%. Under the ESD targets for 2020, those MS with the lowest GDP per capita are allowed to increase their emissions to facilitate their continued economic development.

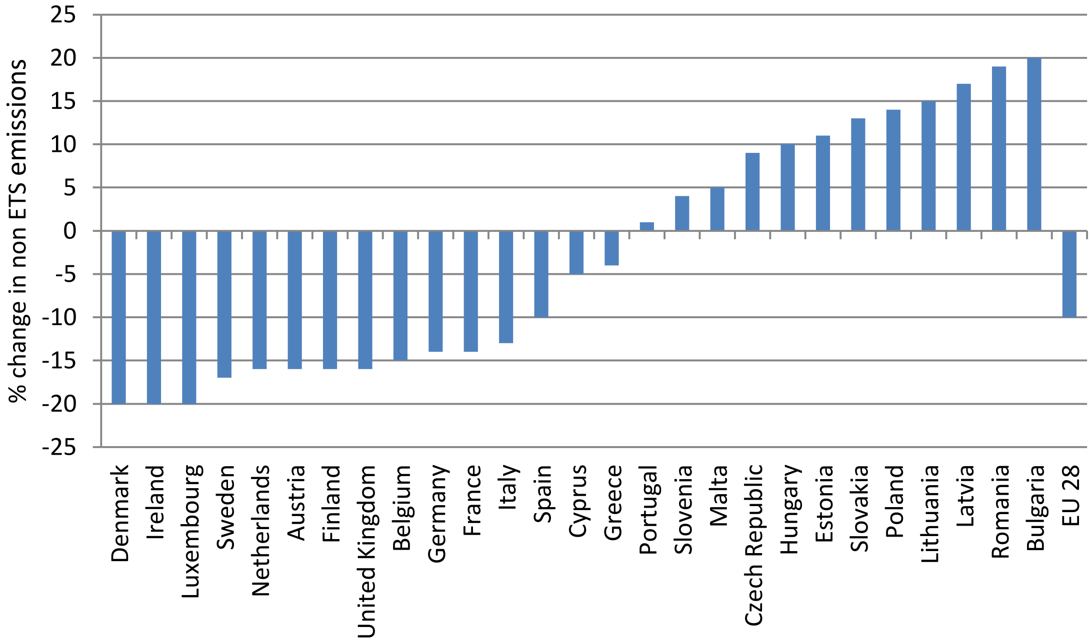

Figure 1. Member States Non ETS GHG emission targets for 2020 (relative to 2005). Source: Decision no. 406/2009 of the European Parliament and the Council

Looking ahead to 2030, the EU has agreed an aggregate reduction in total GHG emissions of 40% relative to the 2005 level. This would be achieved via a 43% reduction in ETS emissions and a 30% reduction in non ETS emissions. Negotiations are on-going with respect to the allocation of the member state ESD targets for the non ETS sector for 2030. No agreement has yet been reached, but policy makers intend to have an ESD in place for 2030 at some point in 2016. If this non ETS sector ESD for 2030 for were based solely on GDP per capita, with the maximum MS GHG reduction set at 40% and the minimum reduction set at zero, then once again Ireland and the UK would receive reduction allocations that are above the EU average, with a reduction target of 37% for Ireland and 35% for the UK, as illustrated in Figure 2 (Graichen et al., 2016).

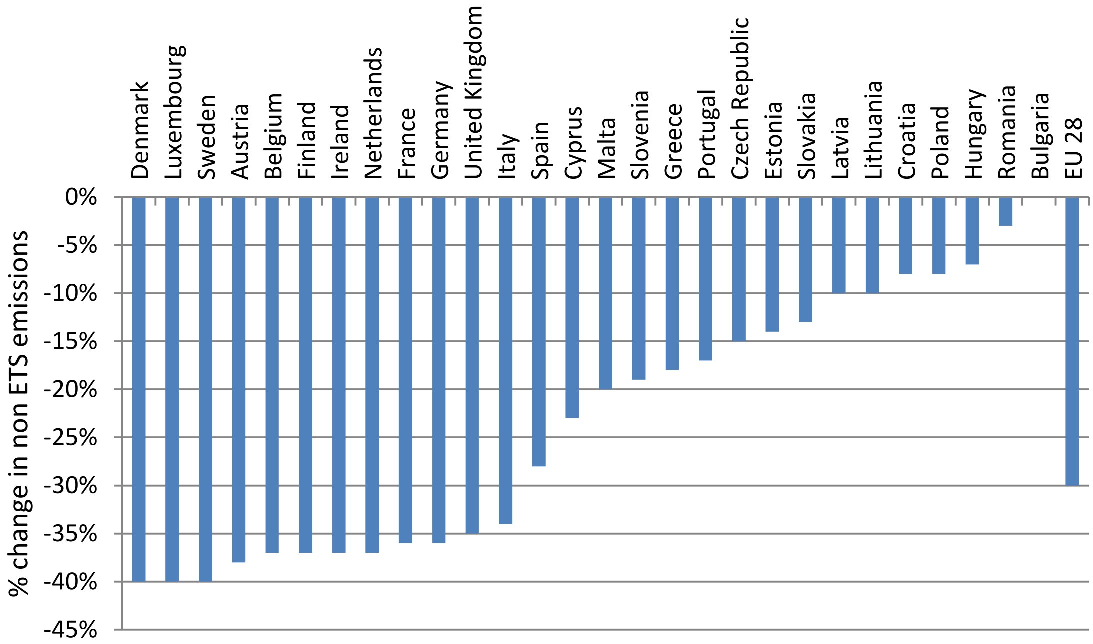

Figure 2. Indicative GHG reduction targets for 2030 (relative to 2005) using a GDP per capita distribution key to allocate Effort Shares. Source: Graichen et al. 2016

Were the outcome of the ESD negotiations for the 2030 reduction target to correspond with the reduction targets illustrated in Figure 2, then this would present a considerable challenge for the non ETS sector in both the UK and Ireland. As we describe in the following section, agriculture represents a significant proportion of non ETS emissions for the UK, and particularly for Ireland, and the sector could therefore come under pressure to achieve a very substantial GHG emissions reduction by 2030, but the policy implications are likely to differ between the two states.

3. Agricultural greenhouse gas emissions in the UK and Ireland

3.1 Ireland

In the 1990s and much of the 2000s, the Irish economy went through a boom period with exceptional levels of GDP growth and employment growth. This growth benefitted both urban and rural areas. The strong growth of the non-agricultural economy contrasted with the relatively stagnant position of primary agriculture. Accordingly, the importance of primary agriculture as a contributor to GDP declined and there was limited political interest in the future development of the sector.

This situation changed rapidly following the global economic downturn of 2008/2009 and the subsequent increase in unemployment that was experienced in Ireland. Observing the commodity price boom that was taking place the Irish government developed a rural employment oriented plan for the agri-food sector in 2009 known as Food Harvest 2020

(DAFM, 2010), which has since been updated in 2015 by a successor strategy document FoodWise 2025 (DAFM, 2015).

Notwithstanding the decline in commodity prices in 2015/2016, the medium term outlook for agriculture is relatively positive. The ending of the milk quota regime marks a major policy change which will allow Ireland's most profitable agricultural sector to grow.

Total Irish GHG emissions grew through the 1990s reflecting the effect if increased income per capita and strong population growth. Emissions from the transport sector in Ireland increased substantially. There has been a brief recession induced hiatus in the last 5 years due to downturn in road freight and commuting to work. Emissions from the energy sector have fallen, due in the main to greater energy efficiency and a shift away from fossil fuels towards renewables. By 2014 Ireland's total GHG emission had returned to 1990 levels (EPA, 2015a).

In Ireland agricultural GHG emissions comprise about one third of all GHG emissions produced across the economy (EPA, 2015a). This is due to the sector being heavily oriented towards bovine agriculture. In addition Ireland has a large cattle population relative to the human population, giving the dairy and beef sectors a large export capacity. The UK represents the largest single market for Irish dairy and beef.

From 1990, Irish agricultural GHG emissions increased in line with the growth in the cattle population which was spurred by the McSharry CAP reforms. Cattle numbers reached a peak in 1999. Thereafter Irish agricultural GHG emission began to fall due to the decline in the cattle and sheep population and a sharp reduction in the use of synthetic nitrogen. Figure 3a shows a decomposition of GHG emissions by sector, and fig. 3b agricultural emissions alone, for Ireland since 1990.

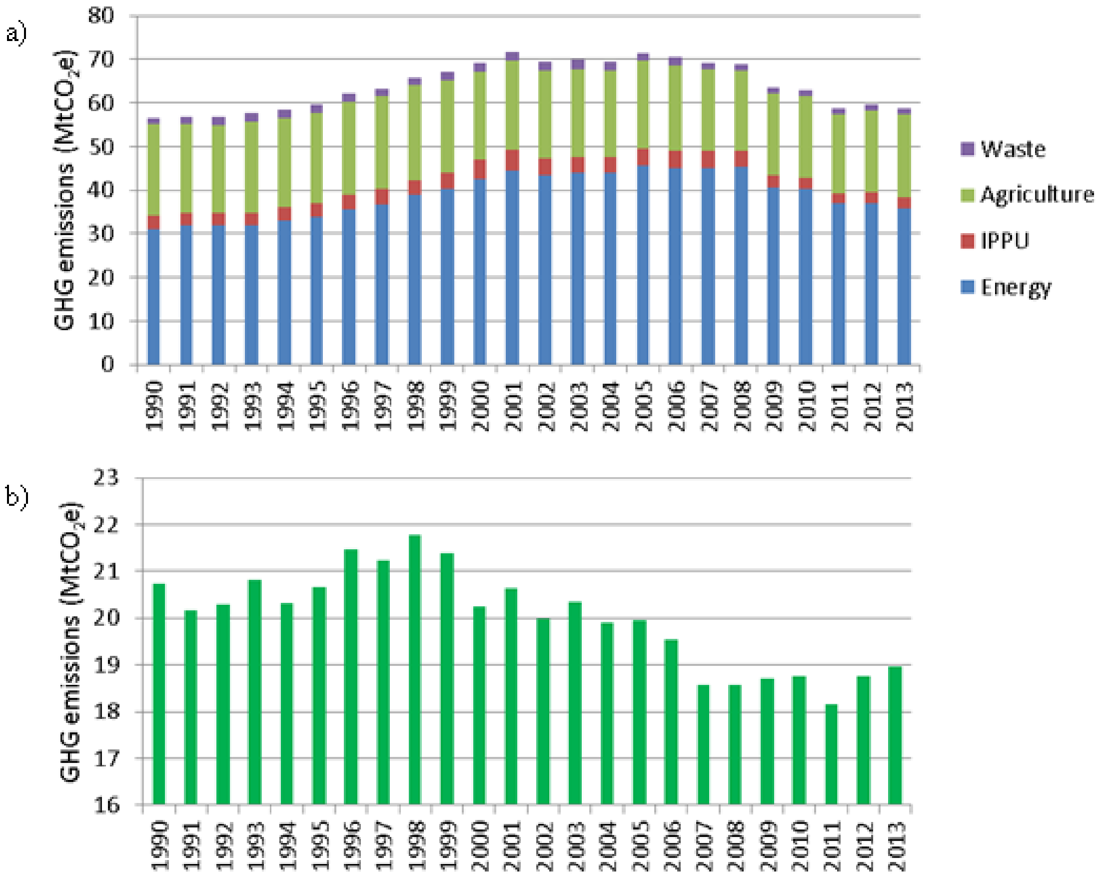

Figure 3 a) Composition of Irish GHG emissions by IPCC sector and b) Irish agricultural greenhouse gas emissions since 1990. Source: EEA (2015)

Within the non ETS sector (decomposition in figure 4 below), agriculture represents an even larger proportion of Irish emissions, at 44% in 2013. The second largest non ETS sector in Ireland is transport, contributing 26% of emissions in 2013. These two sectors dominate the non ETS emissions for Ireland and, as described below, may be expected to form receive reductions targets under the ESD.

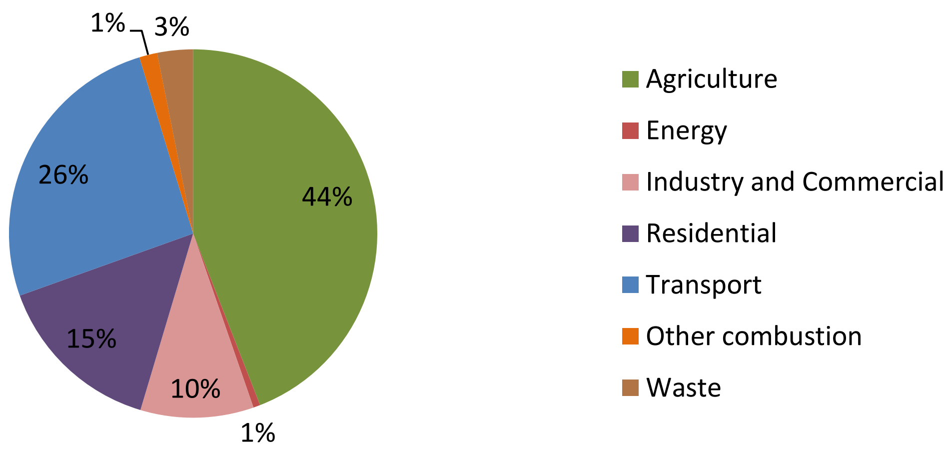

Figure 4. Non-traded emissions composition for Ireland, 2013. Source: Bernard Hyde, EPA, pers. comm.

The composition of the agricultural emissions for Ireland in 2013 are illustrated below in figure 5. Livestock are the dominant source of these emissions, with enteric fermentation from cattle (dairy and drystock) responsible for 51% of all agricultural emissions. The second largest category, direct N_2O emissions (30% of total agricultural emissions), reflects N_2O emissions resulting from a number of processes on agricultural soils. The most important contributing factors are inorganic fertiliser application, application of livestock manures, and N deposition by grazing animals. The remaining agricultural emissions are a result of manure management (a total of 9% of agricultural emissions, again dominated by cattle), indirect N_2O emissions from soil, and small contributions from liming and urea application. Overall, cattle systems are responsible for well over half of Irish agricultural emissions.

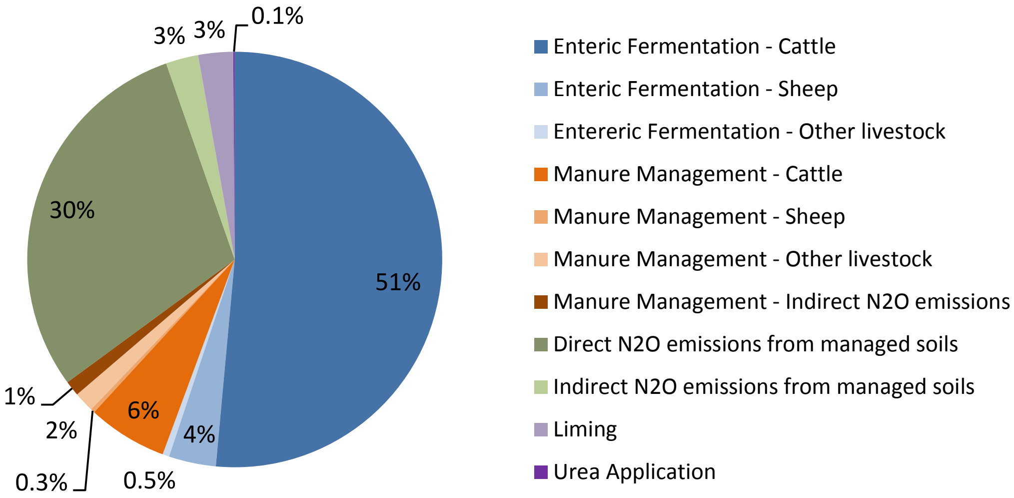

Figure 5. Composition of agricultural GHG emissions for Ireland, 2013. Source: Duffy et al (2015)

3.2 United Kingdom

UK total net greenhouse gas emissions have declined 30% since 1990 (figure 6a). The energy sector is responsible for the majority of UK emissions, and the overall decline is largely due to reductions in this sector, as a result of efficiency improvements in power stations, a trend towards natural gas power generation rather than oil and coal, and increases in the amount of energy generated from non fossil fuel sources. Agriculture is the second largest emissions category in 2013, forming 8.7% of total emissions, and has declined 18% over the period 1990-2013 (fig. 6b). In contrast to Ireland, where large variations in agricultural greenhouse gas emissions were noted as a result of policy changes, UK agricultural emissions have overall shown a gradual decline as a result of lower livestock numbers and a reduction in synthetic fertiliser applications (fig. 6b).

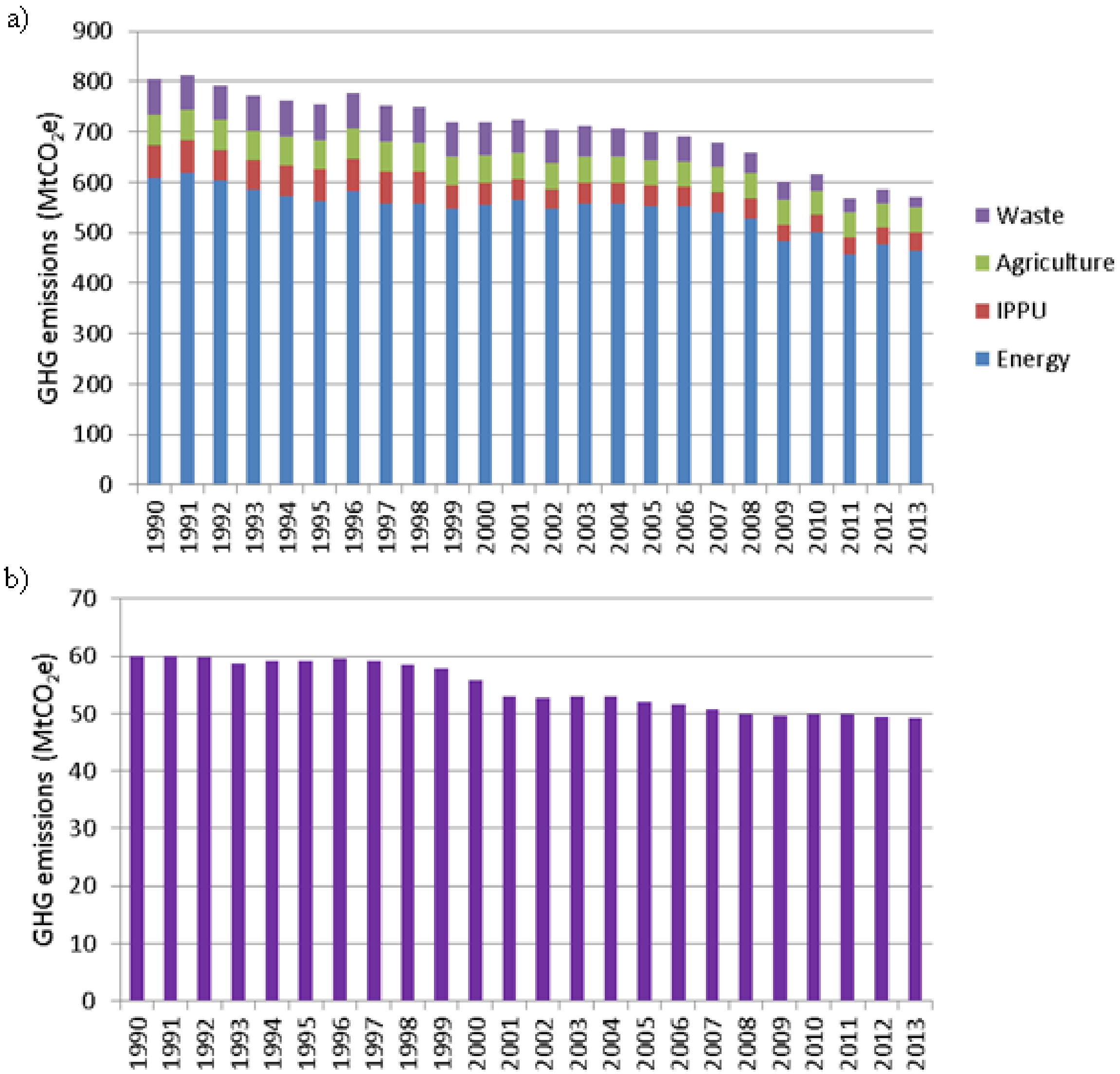

Figure 6a) Composition of UK GHG emissions by IPCC sector and b) UK agricultural greenhouse gas emissions since 1990. Source: EEA (2015)

In common with Ireland, agriculture represents a large share of non ETS emissions in the UK contributing 16% of emissions, and is the third most important sector after transport (34%) and the residential sector (22%). This composition differs significantly between the constituent countries (figure 7). In Northern Ireland agriculture represents 40% of non ETS emissions in 2013, close to the 44% noted for Ireland. The proportion for England is much lower (12%), while Scotland and Wales are intermediate. As in Ireland, transport is also a large contributor to non ETS emissions – either the most or second most significant source in each country.

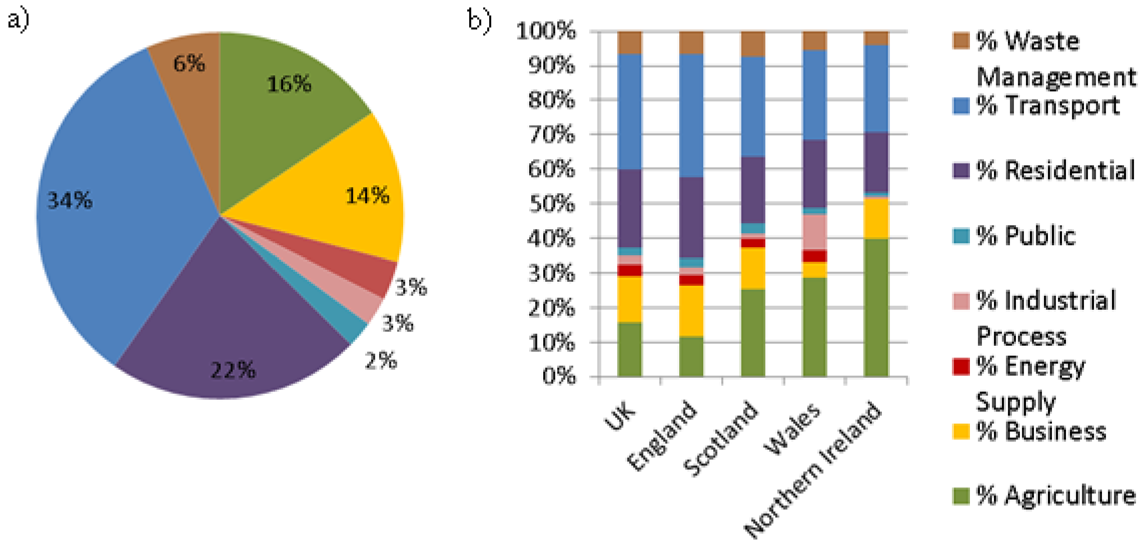

Figure 7. Non ETS emissions compositions for a) the UK and b) the UK and constituent countries in 2013. Source: Salisbury et al (2015)

The composition of the agricultural emissions for the United Kingdom in 2013 are illustrated below in figure 8. Enteric fermentation in cattle is the single biggest source, contributing 38% of total emissions, but is a smaller proportion than in Ireland. Direct N_2O emissions from agricultural soils are again the second largest category, responsible for 31% of agricultural emissions. Manure management (overall approximately 11% agricultural emissions) and indirect N_2O emissions from agricultural soils (8%) are both slightly larger than their respective proportions in Ireland, with liming and urea applications similarly low. Overall, the composition of agricultural emissions in the UK is broadly similar to that of the Ireland, with livestock and particularly cattle responsible for over half of emissions. However, in the UK cattle emissions are slightly less dominant owing to a relatively smaller proportion of cattle systems (dairy and livestock) in the UK – with crop, other livestock and sheep relatively larger sectors than in Ireland (see fig. **X**, comparative production returned to below).

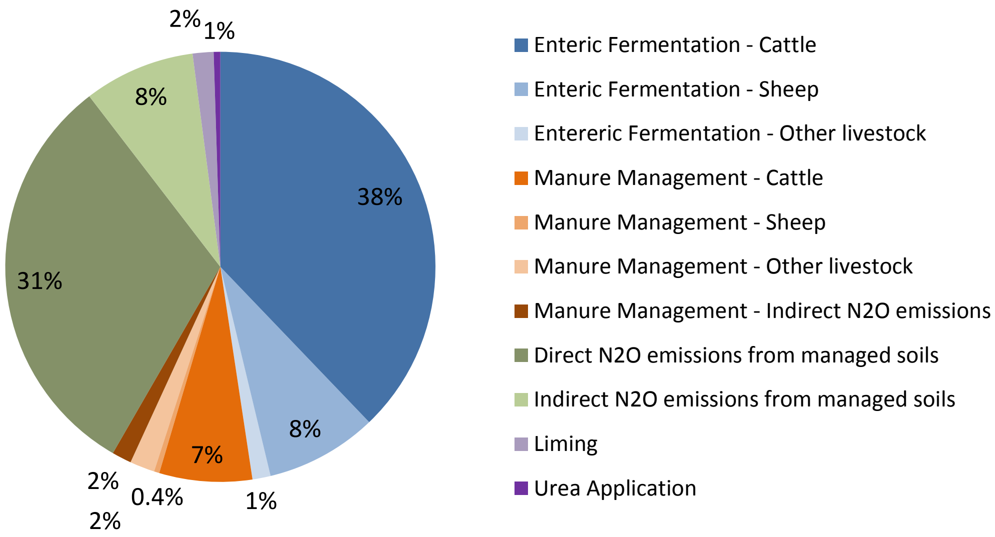

Figure 8. Composition of agricultural GHG emissions for the UK, 2013. Source: MacCarthy et al (2015)

4. Agricultural greenhouse gas emissions and reductions targets

The share of national GHG emissions that arise from the agriculture sector varies greatly by member State (MS) across the EU as illustrated in Figure 9. Ireland is an outlier in that emissions from the agriculture sector comprise 32% of the total. The EU28 average is just below 10%. The UK is below the EU average at 9%. However, when the UK is decomposed into England, Scotland, Wales and Northern Ireland, only England at 7% is below the EU average, while Scotland (15%) and Wales (11%) are above average, and Northern Ireland is much further to the right of the distribution (29%) forming an outlier with Ireland.

GHG emissions from agriculture are a relatively low share of UK total GHG emissions in part because the UK has a sizeable crop sector which generates fewer emissions per hectare than bovine agriculture. The UK in also a net food importer and would have a larger absolute level of agricultural GHG emissions if it were self-sufficient in its food requirements

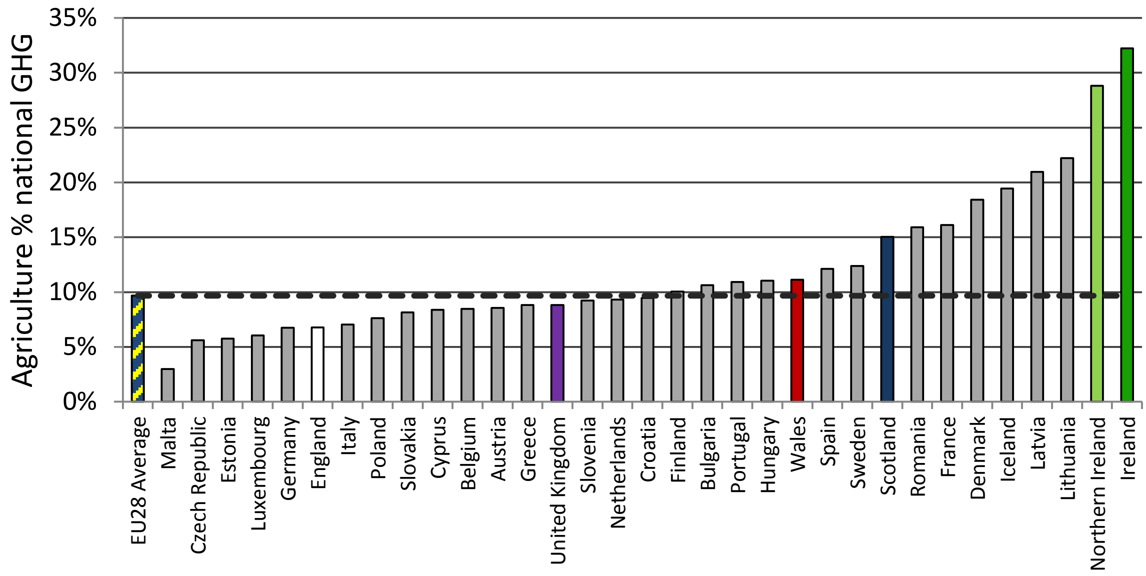

Figure 9. Agricultural emissions as a share of MS total emissions, excluding LULUCF (Land Use, Land Use Change and Forestry) 2013. Sources: EEA (2015) and Salisbury et al (2015)

Agriculture and transport are the two largest contributors to non ETS emissions in Ireland (fig. 4). Although there are a number of technical and behavioural measures that may contribute to transport emissions reductions (NESC, 2015), they appear unlikely to curtail emissions for the sector, and current projections, even under an additional measures scenario, are for a 9% increase on 2005 levels to 14.25 MtCO_2e (EPA, 2015b). Therefore, the agriculture sector is likely to be under pressure to reduce its emissions in Ireland. Any assessment of the likely target that would be allocated to the agriculture sector at this time is purely speculative and for simplicity we assume that the agriculture sector is allocated a pro rata reduction in emissions in line with the overall reduction target for the non ETS sector. i.e. a 37% reduction. Using the 2015 (1990-2013) emissions inventories, this would correspond to an agricultural emission target of 12.57 MtCO_2e for Ireland: a reduction of 7.39 MtCO_2e from 2005 levels.

Later in the paper we examine to what extent reduction target of this magnitude would impact on the level of agricultural activity in the agriculture sector, taking account of the mitigation capacity that may exist through the use of technical mitigation measures. We will see that even when technical mitigation has been factored in, there would remain a considerable distance to target which would need to be addressed through measures which would constrain the size of the agriculture sector.

The UK has its own climate change legislation, the Climate Change Act 2008. The act sets a 2050 emissions reduction target of 80% from 1990 levels. Progress towards this long term goal is made through a series of five-year carbon budgets. The budgets are intended to provide a path for each sector to reduce emissions in the most cost-effective manner, based on current and projected technical and policy measures (Committee on Climate Change, 2015a). So far, UK emissions are below these budgets, and also below the UK annual emission cap under the EU Effort Sharing Decision to 2020 (DECC, 2015a). The 2030 Effort

Sharing Decision target speculated above would come under the UK Climate Change Act fifth carbon budget, which sets a target of 1765 $MtCO_2e$ for the period 2028-2032 (Committee on Climate Change, 2015b). Within the fifth budget period, the central scenario estimates non ETS emissions for 2030 of 227 $MtCO_2e$, below the speculated 2030 target of 247 $MtCO_2e$, a 35% reduction on 2005 levels (Committee on Climate Change, 2015c). As shown in figure 10 below, there is not an equal proportional reduction for all sectors. In particular, the transport sector is shown to be able to reduce emissions by 44% of current emissions, as a result of efficiency improvements in conventional vehicle improvements, uptake of ultra-low emission vehicles, and an increase in the use of biofuels, despite a net increase in the demand for road travel (Committee on Climate Change, 2015c). The decline in agricultural emissions is, in comparison, a much smaller proportion at 14% of current emissions to 46 $MtCO_2e$ (Committee on Climate Change, 2015c). Although this reduction will still be a challenge, it is suggested below that it can be reached through adoption of technical measures alone, without the need for significant production constraints as speculated for Ireland.

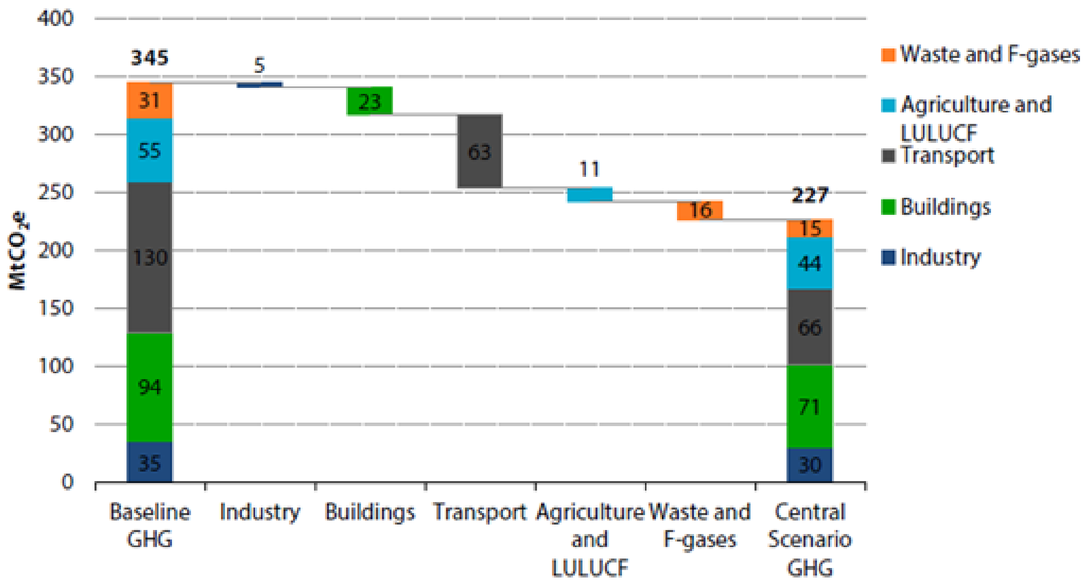

Figure 10. Greenhouse gas abatement in the CCC central scenario for the non-traded sector in 2030. Figure from Committee on Climate Change (2015b)

5. GHG emissions reductions in Ireland and UK through technical means

In this section we examine the work that has been undertaken to assess the future GHG mitigation potential of the agriculture sector in both the UK and Ireland.

Ireland

While Ireland has a Climate Action and Low Carbon Development Bill (Ireland, 2015), it does not have GHG emission reduction targets for individual sectors such as agriculture. A Marginal Abatement Cost (MACC) has been developed for the overall economy (SEAI,

2009) which included mitigation options in the agriculture sector. However, the agricultural element of that MACC was superseded by a specific MACC for the agriculture sector (Schulte et al., 2012) which provides more detailed estimates of the extent of the mitigation that might be delivered by various technical measures and the associated cost. A range of interventions were examined including, genetic improvements, an extended grazing season, manure management practices, nitrification inhibitors, minimum tillage, cover crops, bio energy crops and anaerobic digestion. The MACC is limited to a single scenario where zero cost mitigation of 2.5 $MtCO_2e$ by 2020. This would represent a mitigation potential equivalent to about 10% of the emission produced in 2005. An additional 0.5 $MtCO_2e$ could be achieved at relatively low cost, with all other mitigation measures is excess of €100 per tonne of CO_2e. However, in the absence of mitigation measures, GHG emissions from the agriculture sector in Ireland are projected to increase due to the expansion of the dairy sector following the elimination of the milk quota system. This means that even when all zero cost mitigation measures are included, the overall reduction in Irish agricultural GHG emissions relative to the 2005 would only about 5% by 2020 is projected to be achieved.

An updated MACC for Irish agricultural GHG mitigation, with a 2030 horizon point, is being developed, but there is no quantification at this time of the mitigation potential that might exist by 2030. For the purposes of the paper it is assumed that the mitigation achieved by 2030 would leave Ireland's agricultural GHG emissions at 10% below the 2005 level. Any additional mitigation in the sector would therefore need to be achieved through adjustments in the level of agricultural activity in the agriculture sector in Ireland by 2030.

The other main element of the non-ETS sector in Ireland is the transport sector. Emissions from this sector increased by 180% in the period 1990 to 2008. The post 2008 recession caused those emissions to decrease by 23% in the period 2008 and 2012. However, as the Irish economy has now returned to growth, transport emissions are once again on the increase and are projected to increase further in the coming years.

Overall, by 2020 Ireland is projected to be 6 to 11% below its non-ETS level in 2005, whereas the required ESD reduction target is 20% (EPA, 2016). Looking ahead to 2030, transport emissions are likely to be difficult to contain and this would mean that agriculture could be tasked with a significant requirement to contribute to non-ETS emissions reductions in Ireland.

United Kingdom

In the UK, an agricultural industry Greenhouse Gas Action Plan has set targets for each nation to reduce agricultural greenhouse gases. Relative to 2008, the year of the UK Climate Change Act, targets for 2020 were for England to decrease agricultural emissions by 3 $MtCO_2e$, Wales by 0.6 $MtCO_2e$, Scotland 1.3, and Northern Ireland 0.276; 5.176 $MtCO_2e$ for the UK as a whole (HGCA; Collison and Hillier, 2012). Under the GHG Action Plan, the expectation is for these reductions to be achieved through adoption of technical improvements and more efficient management relevant to different agricultural sectors (ADAS et al 2012). The GHG action plan includes measures to improve crop nutrient and health management, livestock health, energy efficiency and on-farm renewables, improved genetic potential, reduced emissions from the production farm products, and training and advisory services to communicate this information. Although agricultural emissions have only declined slightly since 2008 (fig. 6b), so far the UK has been achieving greater reductions in non ETS emissions than required as part of the ESD, so agricultural emissions would not be under pressure to significantly decrease in order to meet ESD targets for 2020.

The 5th carbon budget baseline projection estimates 2030 UK agriculture and LULUCF (Land Use, Land Use Change and Forestry) emissions of approximately 55 MtCO_2e (Committee on Climate Change, 2015c), based on the DECC projection of 50.02 MtCO_2e (DECC, 2015b), revised upwards due to reassessment of the potential for growth in the dairy sector. It is suggested that an abatement potential of 11 MtCO_2e (8.5 from agriculture and 2.4 from afforestation and agroforestry) could reduce this to 44 MtCO2e (fig x). Of the agricultural sector abatement, it is assumed that 2.6 MtCO_2e is achieved by carrying out the actions as stated in the GHG Action Plan (revised down from the targets listed above, based on current evidence). A further abatement of 6 MtCO_2e (approx.) was considered feasible under the central scenario assuming a strong policy framework to promote uptake of measures. The analysis built upon a UK agricultural MACC to 2030 using the central UK policy carbon price of £78 t CO2e (Eory et al, 2015), along with some additional measures. 2.7 MtCO_2e of this abatement is from crop and soil management, covering precision farming of crops, improved manure application planning, grass clover crops, the use of controlled-release fertiliser, growing GM crops with enhanced nitrogen use efficiency, increasing triticale production, and loosening compacted soils. A further 2.4 MtCO_2e were measures relating primarily to livestock systems: improving cattle and sheep health, improved animal nutrition, using probiotics and nitrate additives in livestock diets, balanced breeding goals, increased use of anaerobic digestion, and slurry acidification. Finally, an abatement of 0.9 MtCO_2e was suggested through improved housing, drying, and other general on-farm activities increasing fuel use efficiency. There remain significant challenges in implanting these practices, and the 2015 Committee on Climate Change progress report highlights the need for the agricultural sector to strengthen and develop indicators the current GHG Action Plan, and co-ordinate efforts between devolved administrations to ensure on-going emissions reductions (Committee on Climate Change, 2015a). However, as noted above, the overall non ETS reduction target is in excess of that likely to be imposed by the ESD to 2030, and so there is not a need to impose additional emissions reductions through reductions or changes in agricultural production.

6. Sectoral economic performance within agriculture in Ireland and the United Kingdom

From an economic perspective, it would be more efficient to constrain those parts of the agriculture sector which are least profitable. This would ensure that within the agriculture sector the cost of mitigating a given volume of GHG emissions was kept to a minimum. We therefore now turn to the profitability of the agriculture sector, looking at Ireland, the UK and the four UK administrative regions of England, Scotland, Wales and Northern Ireland.

Agriculture in Ireland and the UK and its constituent regions differ both in the composition of agricultural output across different commodities and the related importance of subsidies in agricultural sector income. In broad terms, agriculture in Ireland, Wales and Northern Ireland is more dependent on animal and animal product output, while crop output is of greater importance in Scotland and England. The dependence of agricultural sector income (Operating Surplus) on subsidies also differs between Ireland and the regions of the UK (England, Scotland, Wales and Northern Ireland). Taking 2013 as an example, England has the lowest dependence on subsidies (37%), while at the other extreme, almost all agricultural sector income (98%) in Wales was accounted for by subsidies.

In Figure 11 we allocate agricultural output (exclusive of forage plant output) into four categories: cattle (including dairy), sheep, other livestock (pigs, poultry, equines and other animal products) and crop output. This breakdown of agricultural output shares illustrates the greater importance of ruminant based agriculture in Ireland, Wales and Northern Ireland and the importance of crop production in England and Scotland. Non-ruminant animal and animal product output (Pig, Poultry and Eggs) accounts for less than 10% of agricultural output in Wales, Scotland and Ireland, but accounts for over 20% of output value in England and Northern Ireland.

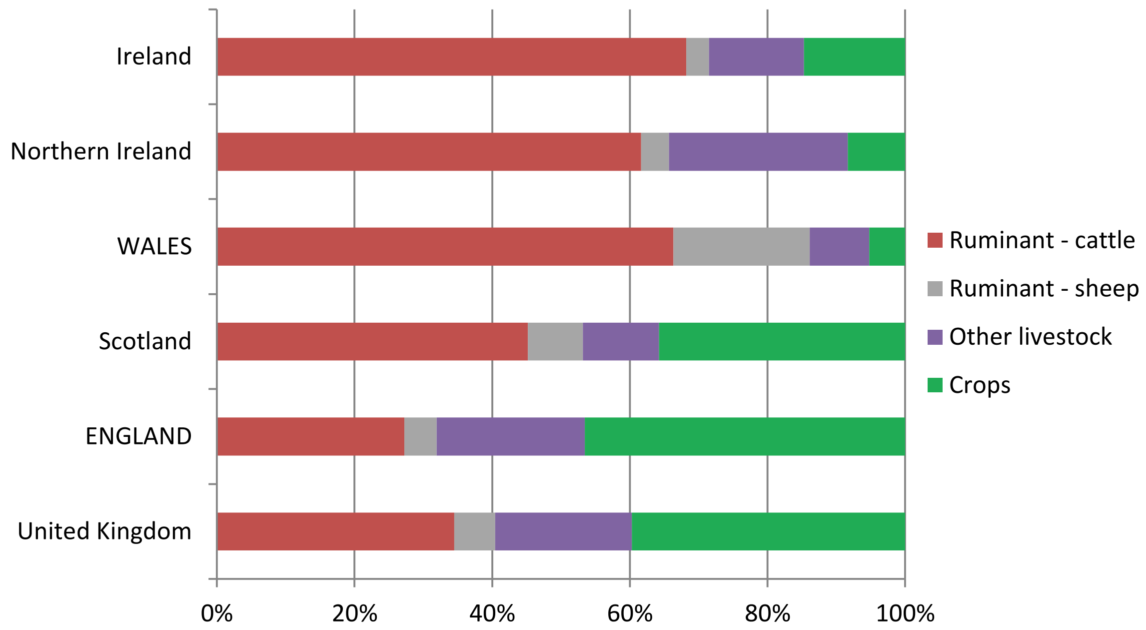

Figure 11. Cattle, sheep, other livestock and crop shares of Agricultural Output. Source: Eurostat dataset agr_r_accts. Note: cattle includes milk and drystock, other livestock includes non-ruminants (pigs, poultry, equine) and animal products other than milk. Crop output is exclusive of forage.

Data from the FADN public database can be used to confirm the greater dependence of cattle and sheep farming activities on subsidies. In Figure 12, data from the FADN for 2013 are presented on average Farm Net Income (SE420) and average Total Subsidies (SE600) for Ireland and each country in the UK (England (North, East, and West FADN regions), Scotland, Wales and Northern Ireland) for 4 of the main farm types (specialist COP [cereals, oilseeds and protein crops], specialist dairy, specialist cattle, specialist sheep & goats).

The FADN data show that across almost all of the regions that average dairy farming incomes are in excess of the value of subsidies received, but that for most of the other farm types in most regions Net Farm Incomes are less than the average value of subsidies received. In all regions, with the exception of Wales, the average Farm Net Income on the specialist cattle farms was less than the average value of total subsidies received by specialist cattle farms. The average Farm Net Income on specialist sheep farms was less than the value of average subsidy receipts across all regions. Specialist COP farms in Wales and Northern Ireland are not reported by FADN in their Public Database due to insufficiently large sample sizes. The low levels of profitability of the average COP farms in Ireland, the regions of England and Scotland is likely to be replicated on average Welsh and Northern Irish COP farms.

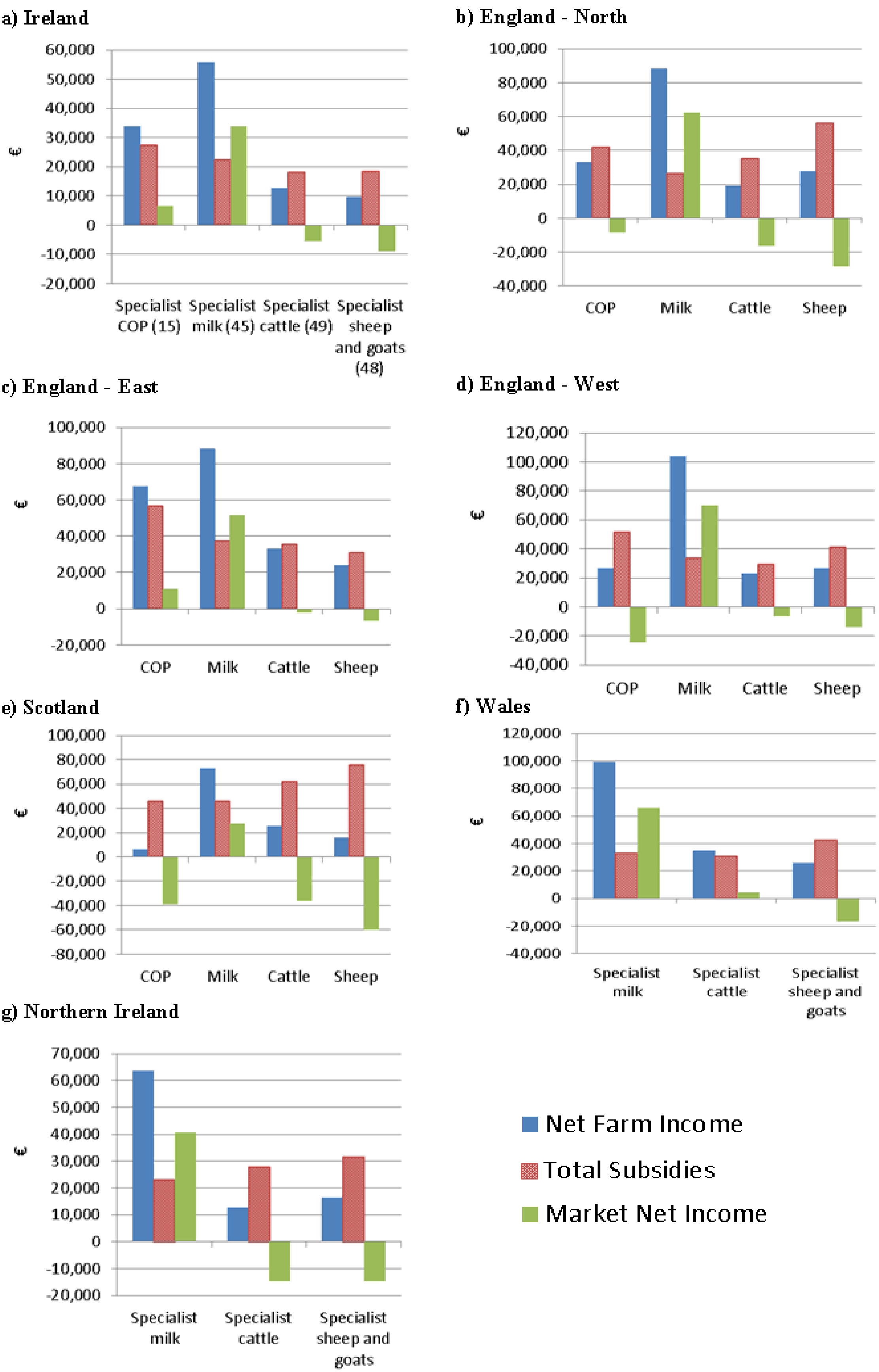

Figure 12. Net Farm Income and Total Subsisdy by FADN farm type for a) Ireland and b-g) UK constituents, 2013. Source: FADN Public Database

A consistent hierarchy of average income per farm across the four farm types is apparent across all of the regions. Net Farm Income on specialist dairy farms is greater than income on specialist COP farms which in turn are greater than incomes on dry stock farms (specialist cattle and specialist sheep and goats). In some regions the average income of specialist cattle farms is greater than specialist sheep and goat farms, while on other the reverse is true. In general in each of the regions the average incomes earned on specialist cattle and specialist sheep and goat farms are very close.

Dependence on subsidies also differs consistently by farm type. In all regions average specialist dairy Net Farm Income is greater than the average value of subsidies received. While in all regions (with the exception of Wales) average specialist cattle Farm Net Income is less than the average value of subsidies received by these farms.

Data from FADN on farm level income illustrate that average dairy farming incomes are consistently higher than average incomes earned from specialist cattle and specialist sheep farms across all UK and Irish regions. This reflects the larger size of dairy farms as compared to cattle and sheep farms in some regions but also the higher levels of income per hectare on dairy farms across all regions. Dairy farms in all regions had incomes in excess of subsidy receipts in 2013. In almost all regions the average income on specialist cattle farms and specialist sheep and goat farms were less than the value of total subsidy receipts. These farm level income statistics highlight the low levels of profitability of drystock cattle and sheep production activities in both the UK and Ireland relative to milk production. In terms of adjustments in the levels of agricultural activity in these regions that might be necessary to meet agricultural GHG emission reduction targets, the loss in value added associated with lower levels of agricultural production activity is likely to be smaller where the activity curtailed is the beef and sheep sectors, rather than the dairy or crops sectors. Combining these differences in profitability with the relative greenhouse gas emissions of different farming sectors (figs. 5 and 8), we focus on the beef sector as a likely candidate for reduced production, as sheep are a smaller contributor to emissions.

7. Production and consumption trends for agriculture in Ireland and the United Kingdom

To what extent will the achievement of non-ETS GHG reduction targets require actions (i.e. changes in agricultural activity levels) over and above the deployment of the technical measures? To assess the "distance to target" likely to remain after the deployment of all currently envisaged technical means of reducing GHG emissions in agriculture it is necessary to have an assessment of the likely level of agricultural activity (and associated GHG emissions) in the UK and Ireland in 2030. The baseline projections of agricultural activity (and associated agricultural commodity supply and use balances and GHG emissions) are generated using the FAPRI-UK and FAPRI-Ireland partial models and provide us with information on the likely evolution of UK and Irish agriculture in the absence of any changes in agricultural and other policies. These models can also be used to assess what changes in agricultural activity levels would be required to reduce agricultural GHG emissions such that with the deployment of all technical measures the emissions from Irish agriculture would be reduced by 37% by 2030.

Under the baseline Irish GHG emissions are projected to grow relative to both their current level and the level in 2005 (the base period under the EU ESD). By 2030 Irish agricultural GHG emissions (exclusive of deployment of any technical means of GHG abatement) are projected to be 1% higher than the 2005 level (see Figure 13). This implies that (exclusive of technical means of reducing emissions) by 2030 Irish agriculture GHG would be almost 64% higher than the target level envisaged under the Effort Sharing Decision.

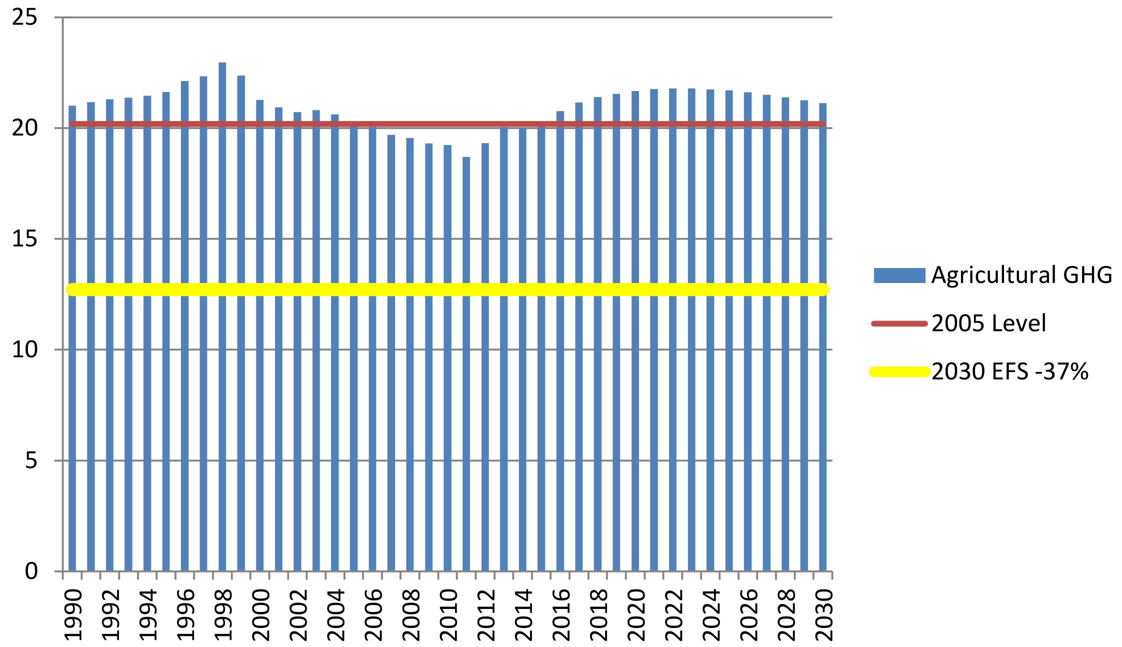

Figure 13. Baseline Irish agricultural GHG emissions to 2030. Source FAPRI-Ireland Model (2016) and EPA (2014)

The principal drivers of the growth in Irish agriculture GHG emissions over the baseline period is the projected strong growth in Irish dairy output and the projected contraction in the Irish suckler cow herd. Figure 14 presents baseline projections of Irish dairy cow and suckler cow ending stocks (December) for the period to 2030.

Under the EU milk quota regime the capacity of the Irish dairy industry to increase production was severely constrained. Increases in per cow milk yields over time led to reductions in dairy cow inventories. Irish suckler cow numbers increased dramatically during the late 1980s and 1990s following the introduction of coupled direct support to beef production (Hanrahan, 2016). Over the baseline projection period, with Irish dairy farmers now free to increase production of milk following the abolition of the milk quota regime, Irish dairy cow numbers and milk yields per dairy cow are projected to increase strongly. By 2030 Irish dairy cow numbers are projected to grow by 26% compared to 2014 levels while Irish milk production is projected to increase by 60% relative to the level observed in 2014.

The projected dynamic growth in Irish dairy cow inventories contrasts with the baseline outlook for the Irish suckler cow herd. Under the baseline real cattle prices in Ireland are not projected to increase. Given the currently low (and often negative) levels of profitability (Hanrahan, 2015), the medium term projections of flat real cattle prices and competition for land from the expanding dairy cow herd, ending inventories of suckler cows are projected to decline. Under the FAPRI-Ireland baseline ending stocks of suckler cows in 2030 are projected to be 34% relative to 2014 levels.

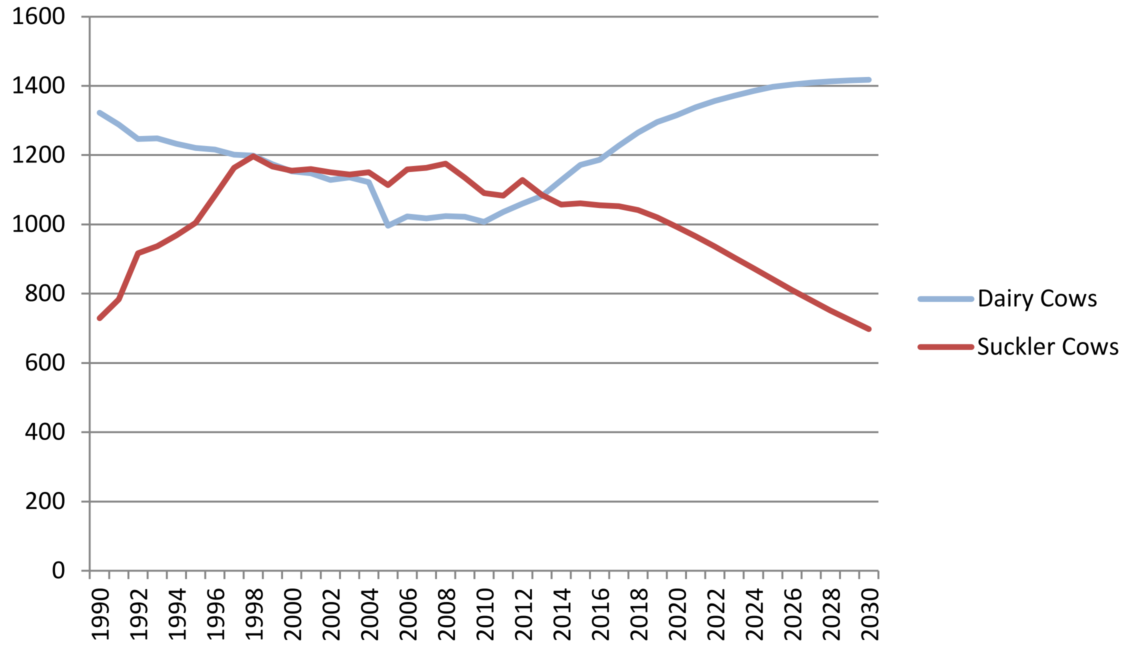

Figure 14. Baseline projected dairy and suckler cow ending stocks. Source: FAPRI-Ireland Model (2016) and CSO

The negative impact of the reduction in suckler cow inventories on Irish cattle inventories, cattle slaughter and beef production is largely offset by the strong growth in Irish dairy cow numbers. By 2030 total Irish ending inventories of cattle are projected to be 5% lower than in 2014. Total cattle slaughter is projected to be largely unchanged on the level in 2014, while the increasing proportion of the breeding inventory accounted for by dairy cows is reflected in a decline in average cattle slaughter weight. Irish beef production in 2030 is projected to be 7% lower than in 2014.

Figure 15 illustrates how the Irish beef supply and use balance is projected to evolve under the baseline. The contraction in Irish beef production is reflected in a contraction in Irish beef exports. Growth in domestic use of beef in Ireland, driven principally by projected growth in population over the baseline projection period, means that by 2030 Irish beef exports are expected to be approximately 20,000 tonnes (5%) lower than in 2014.

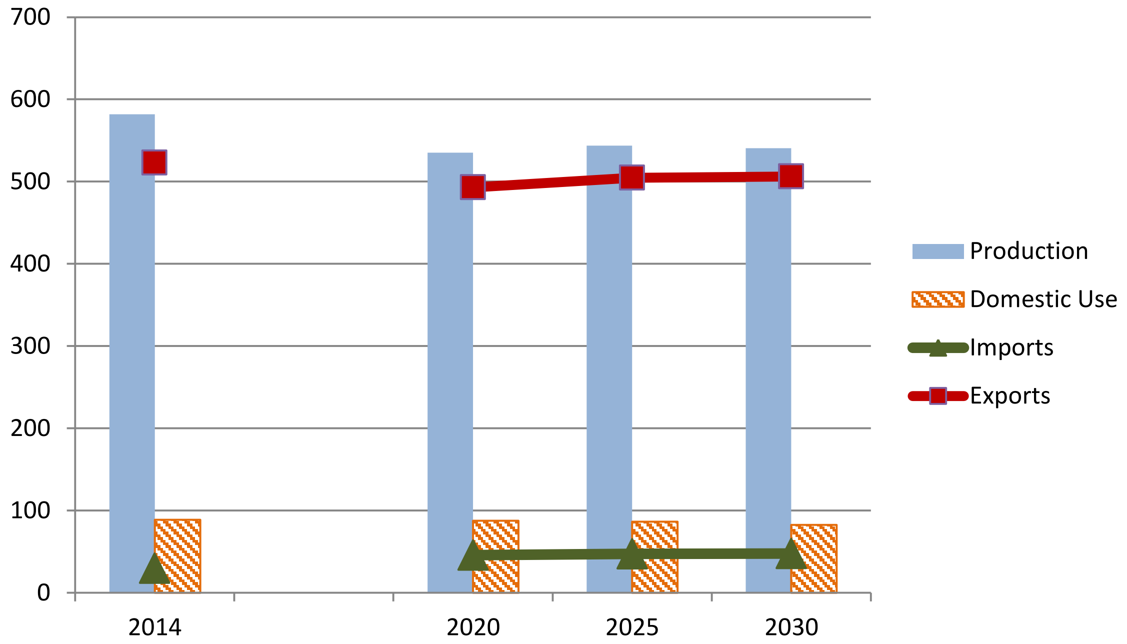

Figure 15. Irish beef supply and use. Source: FAPRI-Ireland model (2016)

Developments in dairy and beef cow inventories in the UK under the baseline contrast with those in Ireland. Over the medium term UK milk production is projected to remain largely unchanged, while projected growth in per cow milk yields is expected to lead to a reduction in total numbers of UK dairy cows of almost 6% by 2025. Ending stocks of suckler cows in the UK are projected to remain stable over the baseline projection period. As a result total inventories of cattle in the UK are projected to decline by only 2%. The increasing share of suckler cows in the total UK cow inventory is also reflected in an increase in the average cattle slaughter weight. UK beef production is projected to decline by only 1% by 2025 compared to 2014.

Growth in the UK population over the medium term is projected to lead to growth in the aggregate demand for beef in the UK despite weak growth in projected UK per capita demand. The growth in the demand for beef in the UK, in the context of the small decline in domestic production, is projected to lead to an increase in UK imports of beef under the baseline. By 2025 UK imports of beef are projected to increase by 16% over 2014 levels to just over 380 kt (carcass weight equivalent). UK baseline beef supply and use developments are presented in Figure 16.

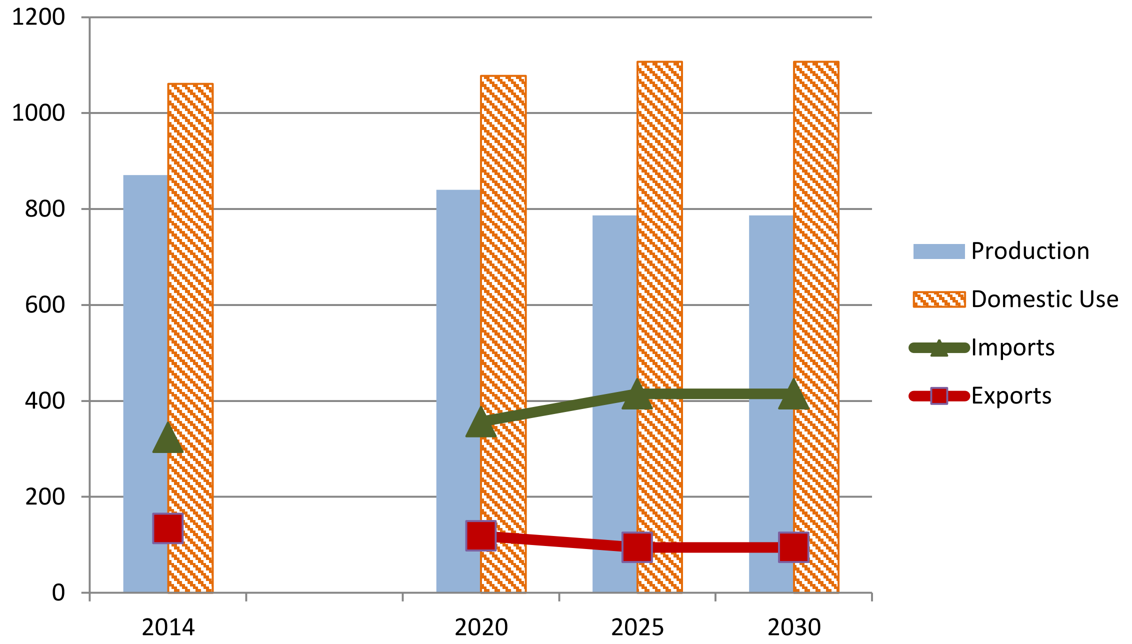

Figure 16. UK beef supply and use. Source: FAPRI-EU model (2015)

With largely stable inventories of bovines and no dramatic developments in other agricultural activity levels projected over the baseline, UK agricultural GHG emissions are projected to remain relatively stable over the period to 2030 (DECC, 2015). In this respect the UK outlook for agricultural GHG emissions contrasts with that in Ireland.

The relatively small share of agriculture within total UK non-ETS emissions means that even if the deployment of technical measures does not deliver all the reductions necessary for emissions from agriculture to fall by an amount equivalent to the percentage reduction in total UK non-ETS emissions, other non-ETS sectors could by reducing their emissions by more than the headline reduction target account for any difference between reductions in UK agricultural emissions and pro-rata non-ETS equivalents. In Ireland, by contrast, the large share of agriculture in total non-ETS emissions means that, if emissions reductions from agriculture are less than that required from the non-ETS sector in general, very large additional non-agricultural non-ETS GHG emission reductions would be required.

The deployment of technical measures in Ireland would at most allow for a 10% reduction in emissions relative to 2005 levels. This is equivalent to approximately 2 $MtCO_2e$. reduction in GHG emissions from Irish agriculture. If the non-ETS reduction target for Ireland of -37% was allocated on a pro-rata basis to Irish agriculture the reduction in agricultural GHG emissions required would be approximately 7.5 $MtCO_2e$. Under the baseline, Irish agricultural GHG emissions are projected to reach 20.4 $MtCO_2e$. which is a 1% increase on the 2005 level. The gap under the baseline to the Irish non-ETS target under by 2030 is projected to be 7.7 $MtCO_2e$. The maximum reduction in GHG emissions from technical measures is understood to be capable of delivering a reduction of 2 $MtCO_2e$ leaving a "gap to target" of 5.7 $MtCO_2e$.

As outlined in section 5 one of the least profitable agricultural production systems in Ireland and the UK is beef production based on specialised beef (suckler) cows. In an alternative scenario we examine the consequences of dramatically reducing the Irish inventory of suckler cows for Irish agricultural GHG emissions, beef production and trade, and in particular trade with the UK. Under this scenario suckler cow slaughter within the FAPRI-Ireland model is artificially augmented so as to reduce the size of the Irish suckler cow inventory and associated progeny. All other agricultural activity levels in Ireland are assumed to remain unaffected. The economic or regulatory drivers of such a development are not explored in this paper. Breen, et al. (2010) discuss the economic differences between command and control versus emission quota approaches to reducing Irish agricultural GHG emissions. Almost certainly large reductions in the number of suckler cows in Ireland would affect other agricultural activity through agricultural land markets effects and via the impact of lower suckler cow numbers on livestock markets. It might be reasonably be expected that such a shock could further increase the size of the Irish dairy cow herd. Levels of agricultural activities in the UK and other EU member states are assumed to be unchanged under the alternative scenario.

Under the alternative scenario, as noted above, the Irish ending stock of suckler cows is reduced to close to zero over the period to 2030 (see figure 17). By 2030 ending stocks of cows are 98% lower than under the baseline. The reduction in Irish suckler cow inventories under the alternative scenario is reflected in smaller annual calf crops, which by 2030 are projected to be 23% lower than under the baseline. The smaller percentage drop in the total calf crop as compared to suckler cows reflects the increased dairy share of total cow inventories under the baseline. The lower suckler cow inventories and lower cattle inventories are reflected in lower volumes of cattle slaughtered, lower average cattle slaughter weights and lower volumes of Irish beef production. By 2030 under the alternative scenario examined, Irish beef production is projected to be 13% lower than under the baseline. Lower Irish beef production is reflected in lower Irish beef exports that are projected to contract by 14% as compared to the baseline level.

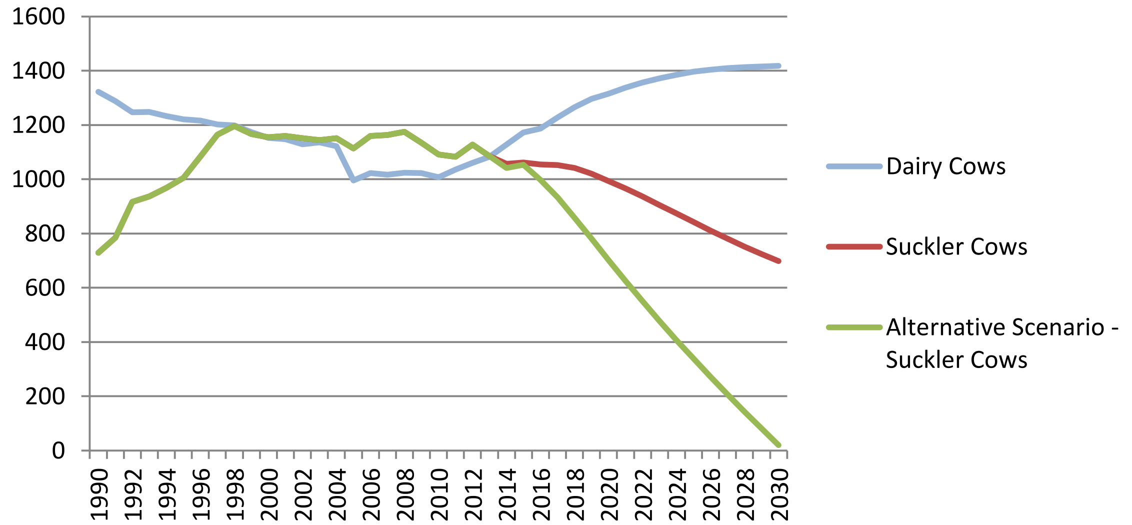

Figure 17. Baseline projected dairy and suckler cow ending stocks. Source: FAPRI-Ireland Model (2016) and CSO.

What impact do these dramatic changes have on Ireland's agricultural GHG emissions? As compared to the baseline level in 2030, emissions under the alternative scenario are 3 M $MtCO_2e$ lower due to the elimination of Ireland's suckler cow herd and associated progeny. However, the level of Irish agricultural GHG emissions is still far in excess of the level implied by a pro-rata application of the non-ETS target for Ireland to agriculture. Technical measures as discussed earlier have the capacity to reduced Irish agricultural emissions by, an assumed, 2 $MtCO_2e$. Thus, even with the elimination of the Irish suckler cow herd Irish and the adoption of all technical measures of reducing GHG emissions from Irish agriculture, the sector's GHG emissions would still be over 2.7 $MtCO_2e$ higher than the level consistent with the achievement of a 37% emission reduction.

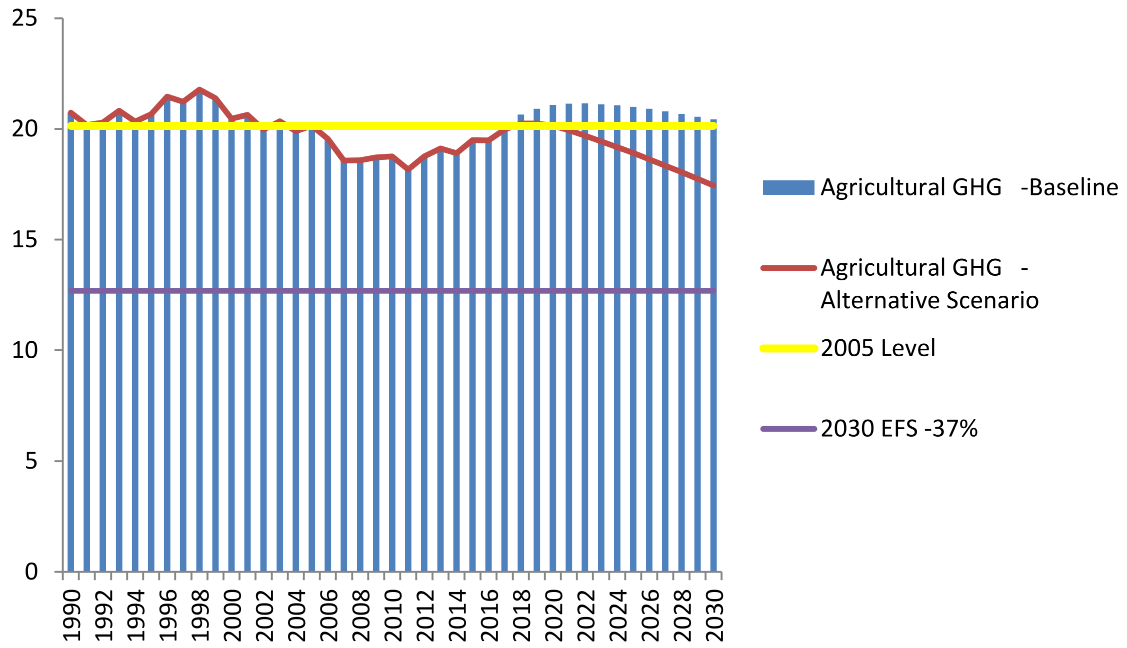

Figure 18. Baseline and alternative scenario: Irish agricultural GHG emissions to 2030. Source: FAPRI-Ireland model (2015)

What are the implications of the dramatic reduction in suckler cow numbers for Irish beef production and for trade in beef between the UK and Ireland? Under the baseline, Irish exports of beef are relatively stable with increases in the dairy cow herd and associated progeny largely offsetting the negative impact of lower suckler cow inventories on Irish beef exports. By 2030 Irish beef exports were projected to reach 523 kt, which represents a 2% increase on the level of Irish beef exports in 2015. In 2015 close to half of all Irish beef exports were shipped to the UK, with the remainder almost exclusively shipped to continental EU markets, while in 2015 imports of beef from Ireland accounted for almost 70% of total UK beef imports.

The level of UK beef imports in 2025 is projected to increase to close to 430 kt. Because both the FAPRI-Ireland and FAPRI-UK models are non-spatial it is not possible to project the Irish share of increased UK beef import demand. However, in the absence of any change in trade policy that increases market access for non-EU beef to the UK and EU markets, it is likely that at least a significant portion of the increase in UK beef import demand under both the baseline and alternative scenarios analysed would be met my increased shipments of beef from Ireland.

Under the alternative scenario the reduction in Irish beef production associated with the elimination of the Irish suckler cow herd reduces the volume of beef available for export from Ireland. By 2030 Irish beef exports are projected to be 14% lower than under the baseline. Given the importance of the UK in total Irish beef exports and the current and likely future status of the UK as Ireland's most valuable export market, it seems likely that Irish exports of beef to the UK under both the baseline and the alternative scenario would increase. This increase in exports to the UK would be driven by the increased UK import demand for beef. With lower volumes of beef available for export from Ireland under the alternative scenario and increased exports to the UK, under the alternative scenario considered the integration of the UK and Irish beef markets deepens. Note that this analysis assumes beef production in continental Europe is unaffected by environmental constraints.

The lower volume of beef production in Ireland changes the supply and use balance on EU beef markets but is projected to lead to only a 2% increase in EU beef prices as compared to the baseline. The relatively small magnitude of the increase in EU beef prices that arises as a result of the dramatic change in Irish suckler cow inventories reflects the relatively small share of Ireland in overall EU beef production. In 2015 Ireland accounted for 6% of EU net beef production (EC, 2016).

8. Conclusions

This paper has examined the implications of potential GHG emissions constraints that could be imposed in the non-ETS sector in the UK and Ireland as an outcome of the GHG Effort Sharing negotiations for 2030. It is clear that the agriculture sector would be required to make a contribution to the achievement of the respective non-ETS reduction targets. While the potential non-ETS reduction targets for the UK and Ireland could be of a similar percentage magnitude, and amongst the largest in the EU, there are clear differences in the implications these reduction targets would have for the agriculture sector in the UK compared to Ireland.

In the UK, the agriculture sector is a relatively small share of aggregate UK non-ETS GHG emissions. Progress in emissions reductions in other areas of the non-ETS sector in the UK look set to place a GHG emissions reduction burden on UK agriculture that is less than proportionate to the overall non-ETS reduction target. This would mean that UK agriculture would not be required to achieve a pro-rata emissions reduction equivalent to the overall non-ETS sector. Technical mitigation should achieve a sufficient reduction in UK agricultural GHG emissions to provide a sufficient contribution to the overall UK non-ETS reduction target. Consequently, the non ETS emissions reduction target would have no effect on the level of agricultural output in the UK.

By contrast in Ireland, the agriculture sector would need to make a very significant contribution to Ireland's non-ETS GHG emission reductions in the period to 2030. Three reasons lie behind this conclusion. Firstly, the agriculture sector represents a large share of non-ETS GHG emissions. Secondly, in the absence of an environmental constraint the outlook is for agricultural production and associated emissions in Ireland to increase in the period to 2030. The third reason is the limited capacity of other non-ETS sectors in Ireland to provide substantial GHG emissions reductions. Consequently, even when technical mitigation potential is included, the non-ETS emissions reduction target could lead to a very large reduction in agricultural activity in Ireland, most likely in the area of beef production. However, the analysis in this paper also shows that a contraction in the Irish beef sector alone could not deliver the required level of GHG mitigation. As a result, the highly lucrative dairy sector would also need to contribute to emissions reductions in Ireland, which would radically hinder the strong post milk quota growth it would otherwise experience.

The reduction in Irish beef output due to the large reduction in the Irish suckler cow inventory reduces Irish beef export volumes. However, given the extremely high degree of self-sufficiency that Ireland enjoys in beef under the baseline, the projected reductions in beef exports of 12% still leaves the share of exports in Irish production at over 90%. UK imports of beef are projected to increase over the medium term and under both the baseline and the alternative scenario analysed the integration of UK and Ireland beef markets is likely to deepen. Even with the projected reduction in Irish beef exports under the alternative scenario Irish beef exports would be sufficient to supply all of the UK beef import requirements – a consequence of any policy that reduces Irish beef production is that it is likely to increase the dependence of the Irish beef industry on the UK market.

The destruction of the Irish suckler cow herd is not the only approach to reducing GHG emissions from the non-ETS sector in Ireland. Alternatively, Ireland could consider substantial afforestation as a means to alleviating the requirement to drastically scale back its agriculture sector in order to contain GHG emissions. However, this would also require that agriculture and forestry (as part of LULUCF), which are currently discrete sectors, would be merged together for GHG accounting purposes, allowing emissions by the agriculture sector to be offset by increasing sequestration by forestry. The means of inclusion of the LULUCF emissions category in the EU 2030 climate policy framework is currently under debate (Böttcher and Graichen, 2015). Alternative policy options could also be considered. Domestically, a policy framework could be put in place to further promote the uptake of on-farm abatement, increasing the number of options identified as cost-effective by the MACC. At the EU level, Ireland may need to argue for a less onerous non ETS reduction target than that speculated above.

References

ADAS, AEA, AHDB, AIC, BPC, CLA, LEAF, NFU, NIAB-TAG, ORC (2012). Meeting the challenge: Greenhouse Gas Action Plan Of the Agriculture Industry in England. Progress report and Phase II Delivery. Available online at http://www.ahdb.org.uk/projects/documents/GHGAPprogressreportApril2012.pdf

Breen, J., Donnellan, T., and Westhoff, P. (2010) Food for Thought: EU climate change policy presents new challenges for agriculture. *EuroChoices* 9(3): 24-29. http://onlinelibrary.wiley.com/doi/10.1111/j.1746-692X.2010.00161.x/epdf

Böttcher, H. and Graichen, J. (2015) Impacts on the EU 2030 climate target of including LULUCF in the climate and energy policy framework. Öko-Institut e.V.

Committee on Climate Change (2015a). Reducing emissions and preparing for climate change: 2015 Progress Report to Parliament. Summary and recommendations. Available online at: https://documents.theccc.org.uk/wp-content/uploads/2015/06/6.738_CCC_ExecSummary_2015_FINAL_WEB_250615.pdf

Committee on Climate Change (2015b). The Fifth Carbon Budget. The next step towards a low-carbon economy. Available online at: https://documents.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf

Committee on Climate Change (2015c). Sectoral scenarios for the Fifth Carbon Budget. Technical report. Available online at: https://documents.theccc.org.uk/wp-content/uploads/2015/11/Sectoral-scenarios-for-the-fifth-carbon-budget-Committee-on-Climate-Change.pdf

DAFM [Department of Agriculture, Fisheries and Food] (2010). Food Harvest 2020. A vision for Irish agri-food and fisheries. https://www.agriculture.gov.ie/media/migration/agri-foodindustry/foodharvest2020/2020FoodHarvestEng240810.pdf

DAFM [Department of Agriculture, Fisheries and Food] (2015). Food Wise 2025. A 10-year vision for the Irish agri-food industry. https://www.agriculture.gov.ie/media/migration/agri-foodindustry/foodwise2025/report/FoodWise2025.pdf

DECC [Department of Energy & Climate Change] (2015a). UK progress towards GHG emissions reduction targets. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/414241/20150319_Progress_to_emissions_reductions_targets_final.pdf

DECC [Department of Energy & Climate Change] (2015b). Updated energy and emissions projections 2015. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/501292/eepReport2015_160205.pdf

Duffy, P., Hanley, E., Black, K., O'Brien, P., Hyde, B., Ponzi, J., Alam, S. (2015). Ireland National Inventory Report 2015. Greenhouse Gas Emissions 1990-2013 reported to the United Nations framework convention on climate change. EPA, Wexford.

EEA [European Environmental Agency] (2015). EEA Greenhouse Gas – Data Viewer. http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

EPA (2015a) Ireland's Provisional Greenhouse Gas Emissions in 2014. Wexford: Environmental Protection Agency. Available online at: http://www.epa.ie/pubs/reports/air/airemissions/GHG_1990-2014_Provisional_11122015.pdf

EPA (2015b) Ireland's Greenhouse Gas Emission Projections 2014-2035. Wexford: Environmental Protection Agency. Available online at: http://www.epa.ie/pubs/reports/air/airemissions/EPA%202015%20GHG%20Projections%20Publication%20Final.pdf

EPA (2016) Ireland's Greenhouse Gas Emissions to 2020 - An update. Wexford: Environmental Protection Agency http://www.epa.ie/pubs/reports/air/airemissions/2020_GHG_Projections_2016_Bulletin.pdf

Eory, V., MacLeod, M., Topp, C.F.E., Rees, R.M., Webb, J., McVittie, A., Wall, E., Borthwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D., Dewhurst, R. (2015) Review and update to the UK Agriculture Marginal Abatement Cost Curve to assess the greenhouse gas abatement potential for the 5th carbon budget period and to 2050. SRUC & Ricardo-AEA. Available online at: https://documents.theccc.org.uk/wp-content/uploads/2016/02/MACCUpdate2015_FinalReport-16Dec2015.pdf

European Commission, 2009. DECISION No 406/2009/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009D0406&from=EN

European Environment Agency http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_-_greenhouse_gas_emission_statistics#Main_tables

European Commission (2016) "Short-Term Outlook for EU arable crops, dairy and meat markets in 2016 and 2017" http://ec.europa.eu/agriculture/markets-and-prices/short-term-outlook/pdf/2016-3_en.pdf

Graichen, J., Graichen, V., Cook, V. (2016). EU effort sharing for the 2021-2030 period. Setting GHG emission targets for EU Member States. Öko-Institut e.V.

Hanrahan, K. (2015) "Review of Cattle Farming in 2015 and Outlook for 2016." in Outlook 2016: Economic Prospects for Agriculture. Teagasc. http://www.teagasc.ie/publications/2015/3777/Outlook-2016web.pdf

Hanrahan, K (2016) "Influence of Market and Policy Developments on Irish Cattle Production and Beef Output." Paper presented at the 2016 Agricultural Economics Society of Ireland Annual Conference, Glasnevin, January 7, 2016.

HGCA [Collison, M. and Hillier, J.] (2012). Understanding carbon footprinting for cereals and oilseeds. Available online at http://cereals.ahdb.org.uk/media/176733/g57_understanding_carbon_footprinting_for_cereals_and_oilseeds.pdf

Ireland (2015) Climate Action and Low Carbon Development Act 2015. Oireachtais

IPCC, 2007 [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.)]. Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge and New York).

MacCarthy, J., Broomfield, M., Brown, P., Buys, G., Cardenas, L., Murrells, T., Pang, Y., Passant, N., Thistlethwaite, G., Watterson, J. (2015). UK Greenhouse Gas Inventory, 1990 to 2013. Annual Report for Submission under the Framework Convention on Climate Change. Ricardo-AEA, Didcot.

NESC [National Economic & Social Council] (2015). NESC Forum: Opportunities & Challenges for Climate Mitigation in the Irish Transport Sector. Available online at: http://www.nesc.ie/assets/files/downloads/Events/Transport-Forum-2015/Transport15_Discussion-Paper.pdf

Salisbury, E., Thistlethwaite, G., Young, K., Cardenas, L., Thomson, A. (2015) Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2013. National Atmospheric Emissions Inventory.

SEAI (2009) Ireland's Low Carbon Opportunity: An analysis of the costs and benefits of reducing greenhouse gas emissions, Dublin: Sustainable Energy Authority of Ireland http://www.seai.ie/Publications/Renewables_Publications_/Low_Carbon_Opportunity_Study/Irelands_Low-Carbon_Opportunity.pdf

Schulte, R.P.O., Crosson, P., Donnellan T., Farrelly, N., Finnan, J., Lalor, S., Lanigan, G., O'Brien D, Shalloo L., Thorne, F. (2012), A Marginal Abatement Cost Curve for Irish Agriculture, Teagasc, Dublin. http://www.teagasc.ie/publications/2012/1186/1186_Marginal_Abatement_Cost_Curve_for_Irish_Agriculture.pdf

Vermeulen, S.J., Campbell, B.M. and Ingram, J.S.I. (2012). 'Climate Change and Food Systems', Annual Review of Environment and Resources 37, 195–222.

World Bank (2012) World Bank report, 'Turn down the heat: Why a 4°C warmer world must be avoided'. Available online at: http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_ world_must_be_avoided.pdf