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HOW FAR CAN GREENHOUSE GAS MITIGATION TAKE US TOWARDS NET ZERO EMISSIONS IN AGRICULTURE?

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Abstract
An increasing number of countries are setting targets for reducing national greenhouse gas emissions to net zero in the coming decades. Such emission reductions will require a transformation of all sectors of society, but nowhere more so than in agriculture and land use (AFOLU IPCC sector). Using the UK as a case study we outline how and to what extent changes in agricultural management could contribute to the net zero target. Agriculture in the UK is responsible for 46 Mt CO_{2e} or 10% of UK emissions (2017). In order to reach an overall target of net zero for the UK economy by 2050 it is estimated that agricultural emissions must be reduced by over 50%. Previous estimates show that on-farm agricultural emissions can be reduced by 10-20%, by implementing a range of technologies that reduce nitrous oxide emissions (including more efficient use of fertilisers and manures, the use of urease and nitrification inhibitors, more extensive use of legumes, and improved soil management) and methane emissions from livestock (including dietary manipulation, use of improved genetics, and improved animal health). Unlike some other sectors, agricultural emissions cannot be reduced to zero, and the land use sector will play a major role in the removal of residual positive emissions. Biomass energy with carbon capture and storage offers the largest opportunity for CO_2 capture, but other approaches such as increased soil carbon sequestration, the use of biochar, mineral weathering, and direct air capture are currently being explored. However, such offsetting mechanisms are also likely to be relied upon by other sectors including aviation in which it is difficult to achieve zero emissions. If offsetting is unable to remove sufficient quantities of GHGs to reach the net zero target, then additional novel measures, such as biochar application, and substantial changes in our food basket to reduce emissions from the agriculture sector will be required.

Background

The Paris climate change agreement established the urgent need to keep global temperature increases to well below 2°C with an aspiration to limit rises to no more than 1.5° C. A more recent analysis by the IPCC has identified multiple lines of evidence demonstrating increased risks of temperature rises above 1.5° C (IPCC 2019). It is concerning therefore that the current international commitments made through the Paris Agreement fall well short of achieving even the 2° C target (Ripple *et al.* 2019). The 2019 IPCC report argues that the global community should embark on deep and immediate cuts to greenhouse gas emissions order to reach net zero emissions by the middle part of the current century. By 2050 emission reductions will need to be combined with large-scale greenhouse gas removal from the atmosphere in order to avoid future rises above 1.5°C (Fig. 1). Although a number of different pathways are possible in order to avoid dangerous climate change they all depend on a radical transformation of the agriculture and land use sectors. This is because the agriculture, forestry and other land use sector is a significant source of greenhouse gases, contributing to around 25% of global emissions. It is essential therefore for agriculture to reduce its greenhouse gas emissions in parallel with other sectors. However, greenhouse gas mitigation alone would be insufficient to meet the 1.5°C target. Integrated Assessment Models now clearly recognise that large-scale removal of greenhouse gases from the atmosphere will need to start within the next decade, increasing significantly during the remaining part of this century (IPCC 2019). Most of the techniques proposed for greenhouse gas removal depend on land use and land use change, but there is clearly a need to balance the demands for greenhouse gas removal with other services provided by land use including the provision of food, wildlife habitats and biodiversity, environmental interactions and social and cultural services. Therefore, the need to develop mitigation targets within the agriculture and land use sector needs to take into account this wider context within which food, feed and fibre production is undertaken.

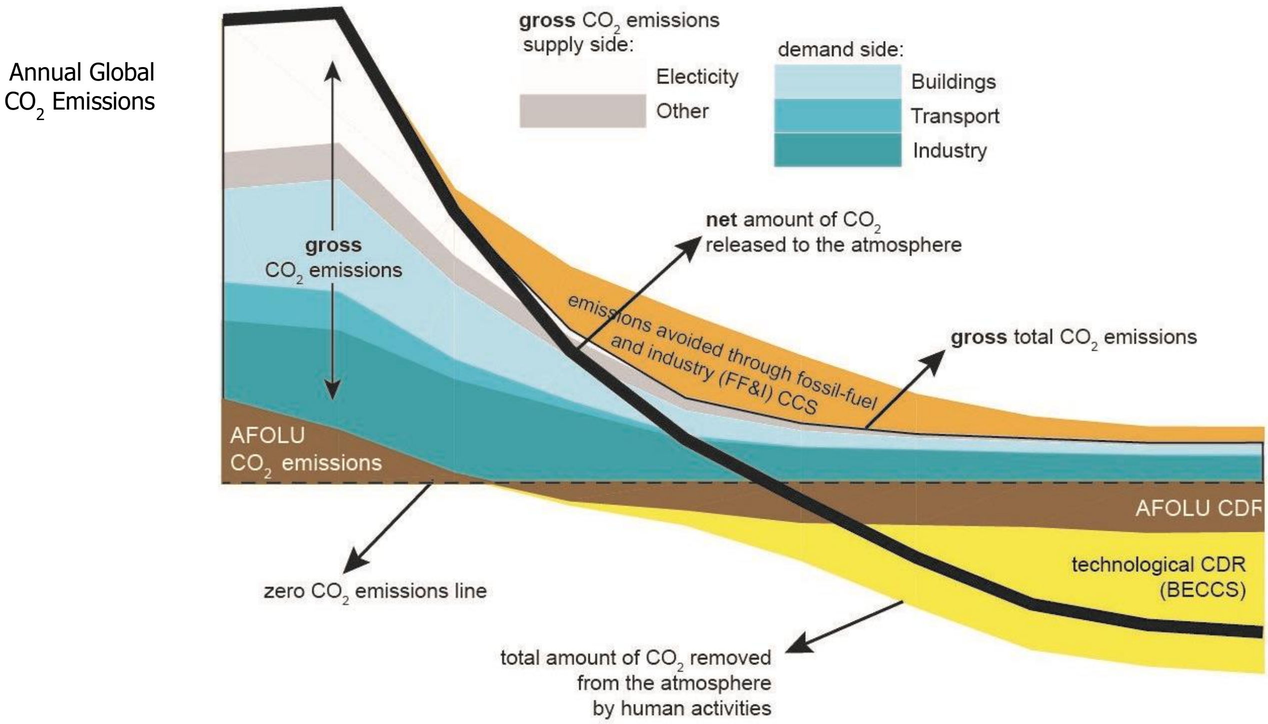

Figure 1. The breakdown of global anthropogenic CO_2 emissions over the twenty first century in a schematic representation of the pathway required to meet an emissions pathway that is compatible with limiting temperature rises to 1.5°C (IPCC 2019).

Following the publication of the IPCC's 1.5°C Report, the U.K.'s Committee on Climate Change (CCC; an independent body that provides advice to government on climate change mitigation targets) recommended that they should "set and vigorously pursue an ambitious target to reduce greenhouse gas emissions to net zero by 2050 (or 2045 in Scotland), ending the U.K.'s contribution to global warming within 30 years" (Committee on Climate Change 2019). In 2019 the UK committed in law to reducing greenhouse gas emissions by 100% of their 1990 levels by 2050 as part of the Climate Change Act (2008). Their targets recognise that in order to achieve the 1.5° C target, global per capita emissions by 2050 need to be in the range of -1.4-0.7 t CO_{2e} y^{-1}. In the UK this would require a reduction in greenhouse gas emissions between 85-104% against 1990 levels with the 100% reduction being equivalent of the net zero target. The CCC also recognise that "if replicated across the world with ambitious near-term reductions in emissions it would deliver a greater than 50% chance of limiting temperature increases to 1.5ºC". A net zero target requires deep reductions in emissions across all sectors, with any remaining sources offset by removals of CO_2 from the atmosphere e.g. by afforestation or biomass energy carbon capture and storage (BECCS). The CCC has identified an opportunity for emissions from the agriculture and land use sector to be reduced from 58 Mt CO_{2e} 2017 to 21 Mt CO_{2e} by 2050, achieving a reduction of over 60% in around 30 years. These emission reductions are expected to be achieved by improved farming practices (10 Mt CO_{2e}) reduced waste and dietary change (7 Mt CO_{2e}), afforestation, agroforestry and other (34 Mt CO_{2e}), energy crops (2 Mt CO_{2e}) and peatland restoration (5 Mt CO_{2e}). An integrated roadmap is proposed in which a series of coordinated activities across different sectors contribute to an economy wide reduction in greenhouse gas emissions. However, given the nature of the measures proposed there will be strong interactions between different sectors. For example, reductions in greenhouse gas emissions from the energy sector are dependent upon new sources of energy provided by biomass will have implications for land use and agriculture.

The extent of the ambition being proposed by the new climate change mitigation targets can be understood by considering changes in the U.K.'s recent emissions of greenhouse gases. Although some sectors have achieved significant reductions in greenhouse gas emissions (for example, industry and energy supply) emissions from agriculture have remained largely constant over the past 10 years, making up around 10% of national emissions (Fig. 2). This corresponds with the low level policy support for greenhouse gas emission reductions over the past two decades in the sector, voluntary mitigation action being the core of government policy.

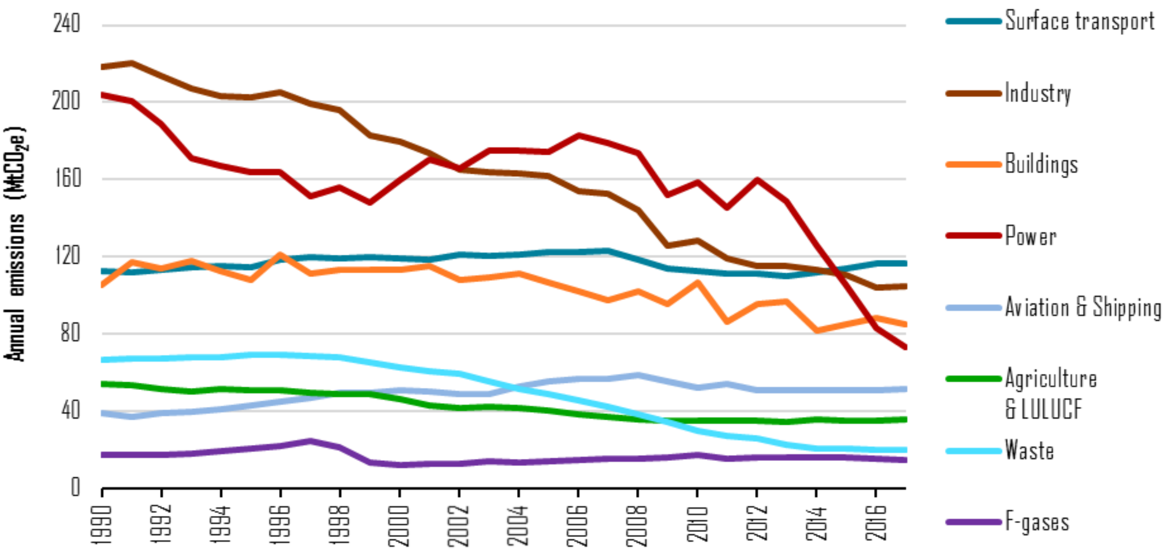

Figure 2. National inventory report of the change in emissions of UK greenhouse gas emissions between 1990-2017 (Brown *et al.* 2019).

Underpinning research

In order to achieve effective mitigation within any sector, it is an essential prerequisite that there is a good understanding of the magnitude and sources of emissions. Agriculture is a notoriously difficult sector within which to accurately quantify greenhouse gas emissions. This reflects the difference between agriculture and land use and many other sectors, with emissions made up largely of nitrous oxide and methane, as opposed to CO_2 from most other sectors, and the fact that they are derived from biological sources with inherently greater variability and uncertainties. For these reasons the UK has recently undertaken a large programme of research to provide improved quantification and reporting of greenhouse gas emissions from agriculture and land use in an integrated research study called the Greenhouse Gas Platform Programme. Over a period of six years the programme undertook measurements and modelling of nitrous oxide from different nitrogen sources, and provided new emission factors for direct fertiliser and manure applications to arable land and grassland and grazing returns from livestock (Bell *et al.* 2015; Cardenas *et al.* 2019; Chadwick *et al.* 2018). In a parallel research project, new emission estimates for methane emissions from the livestock sector have allowed the development of nationally appropriate coefficients that take account of breed and diet (Moorby *et al.* 2015). As a consequence, the UK has now adopted a combination of Tier 2 and 3 reporting system for methane and nitrous oxide from agricultural land use, which forms the basis for improved mitigation policy (Brown *et al.* 2019).

Agricultural Greenhouse gas mitigation

As a part of its commitment to the Climate Change Act (2008), the UK government is required to set carbon budgets at five year intervals. These budgets identify activities that are expected to deliver mitigation in different sectors, directing government to set appropriate policies to ensure that carbon budgets are achieved. Given the lack of any reduction in emissions from the agriculture sector over the past 10 years, mitigation in this sector is now seen as a priority. We know that a wide range of management interventions can reduce greenhouse gas emissions from agriculture (Smith *et al.* 2008). Often these interventions are based around improving the efficiency of resource use in order to achieve better recovery of nutrient inputs, either within the crop or livestock sector. However, given the wide range of interventions and highly variable mitigation potential and costs with which they are associated, it is helpful to provide a logical framework within which to rank the mitigation potential of these different measures. One approach to this is to use marginal abatement cost curves, in which cost effectiveness (£ tCO_{2e}^{-1}) is plotted against abatement potential (kt CO_{2e} y^{-1}; MacLeod *et al.* 2010; Moran *et al.* 2011). Such an approach provides a ranking of measures and advice on the logical sequence of intervention of these measures, cost and carbon abatement potential. A series of marginal abatement cost curve assessments have been undertaken in recent years and shown that around 10-20% abatement potential could be achieved at a cost lower than the carbon cost in the UK farming sector (with many interventions having a negative cost, i.e. achieving both carbon saving and cost saving within individual farm enterprises). In a recent assessment undertaken in 2015, a central feasible mitigation potential (one that assumes a carbon cost of £78 t^{-1} CO_{2e}, and was based on assumed realistic levels of uptake) of 7.1 Mt CO_{2e} by 2035 was estimated (Eory *et al.* 2015). This falls well short of the magnitude of emission reductions that is required given the need to reduce emissions from the sector by 58 Mt CO_{2e} by 2050.

It is therefore likely that more aggressive mitigation will be required possibly resulting in higher costs to support mitigation policy development in this area. It is also possible that former subsidies (earlier provided under the European Union's Common agricultural policy) could be directed towards supporting greenhouse gas mitigation (as a type of 'public good' produced by farmers and land owners), as set out in the proposed Agricultural Bill (House of Commons Library, 2020). The magnitude of emission reductions that is achieved, will influence the amount of greenhouse gas removals that are required in order to meet the net zero target.

Greenhouse gas removals

Soil carbon sequestration removes CO_2 from the atmosphere, adding it to stable pools within the soil (Powlson *et al.* 2011). A wide range of measures such as erosion control tillage operations, of optimising stocking density, extending the perennial phase of crop rotations, optimising soil management, optimising organic amendments and crop residues can help to promote soil carbon storage (Smith *et al.* 2016). However, where land use remains unchanged, accumulation of carbon is often slow or non-existent. A recent analysis of national soil survey data in Scotland showed over an interval of 30 years, there was no significant change in the carbon stock in grasslands and arable farming systems (Chapman *et al.* 2013). A more detailed site-specific study also found no significant change in soil carbon stocks in a pasture based system with detailed observations extending over seven years (Jones *et al.* 2016).

In addition to soil carbon sequestration, other greenhouse gas removal technologies are being investigated, including biomass energy carbon capture and storage, direct air capture, mineral weathering, ocean fertilisation and the application of biochar (Smith *et al.* 2016). Many of these technologies are unproven in terms of their scalability, economics and biophysical potential to capture large amounts of CO_2 from the atmosphere. However, one approach that is particularly appealing to the agriculture sector is the use of biochar given the potential for converting crop residues to biochar carbon in order to stabilise soil carbon storage (Sohi 2012; Weng *et al.* 2018). Given that supply side mitigation and carbon dioxide removal from the atmosphere may well be insufficient to meet the U.K.'s net zero target, further reductions in greenhouse gas emissions from the agriculture sector may need to be achieved by reductions in demand for high carbon intensity products such as meat from ruminant livestock sector and dairy. These products are associated with a particularly high proportion of emissions generated within the sector and therefore provide significant mitigation potential (Ripple *et al.* 2014). A recent study indicated that a 50% reduction in meat and dairy consumption across Europe would lead to a 40% reduction in greenhouse gas emissions (Westhoek *et al.* 2014). The CCC assumed 20% reduction in consumption of these products by 2050, however, for this to be effective in combating the global problem of climate change it would need to be accompanied by a reduction in production (in order to avoid exporting greenhouse gas emissions associated with livestock products).

Balancing mitigation and removals

In order to understand at farm level, how mitigation and carbon sequestration can be combined, we used the AgRECalc© farm model (Sykes *et al.* 2017) to simulate the implementation of a series of mitigation measures (chosen from those identified as being of greatest promise in the recent marginal abatement cost curve assessments). The remaining carbon emissions were then allocated to carbon uptake either by afforestation or biochar application. This study indicated that net zero carbon emissions are possible to achieve within the farm boundary if aggressive mitigation is coupled with measures to increase carbon sequestration, including the application of biochar. This modelling exercise assumed that a typical Scottish farm of 230 ha which included arable and livestock (beef) production has an annual carbon footprint of 1443 t CO_{2e} y^{-1}. The sequential introduction of mitigation measures (improving fertiliser N applications, improving the productivity, use of a methane inhibitor (3NOP), incorporation of legumes within the rotation, the application of nitrification inhibitors) achieved a mitigation of greenhouse gases of around 30% (Fig. 3). The improvements in pasture management allowed some land (15% of the farm area) to be available for tree planting, whilst maintaining existing levels of productivity. The remaining greenhouse gas emissions needed to be removed by the addition of 0.7 t of biochar ha^{-1} y^{-1} which was assumed to be provided by converting 50% of the straw produced on the farm from cereals to biochar.

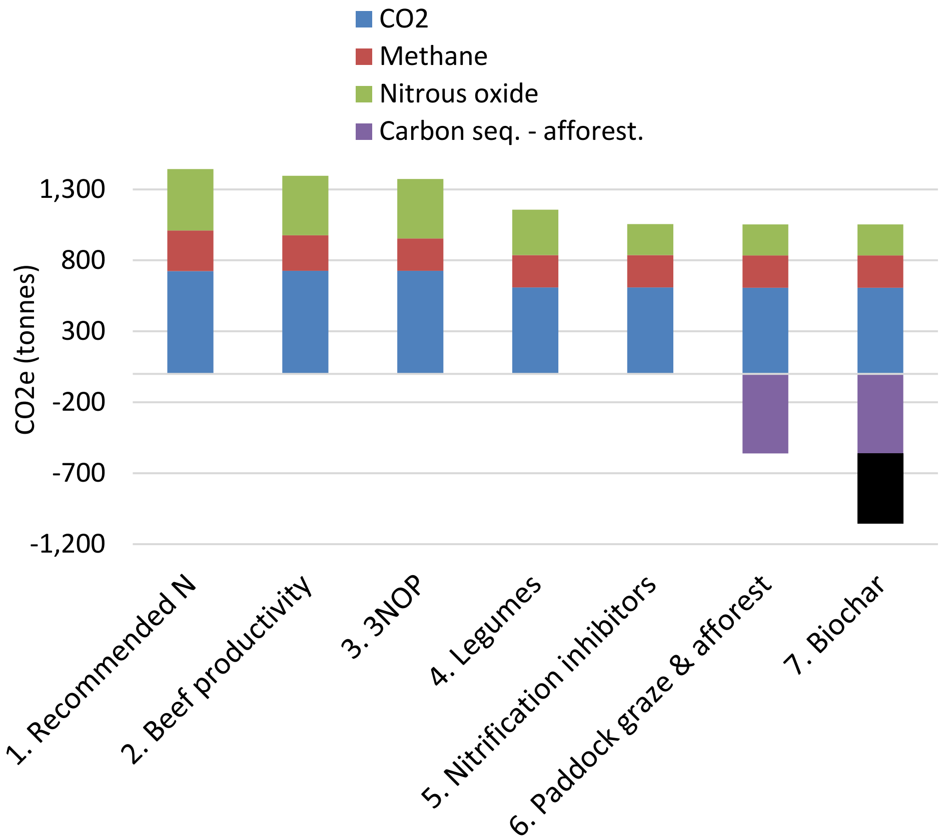

Figure 3. Modelled representation of changes necessary on an individual farm to achieve net zero using the Agrecalc farm greenhouse gas modelling tool. Based on a typical mixed farming enterprise of 300 ha in the south of Scotland.

This study indicates that a series of interventions at the farm scale can theoretically deliver a net zero farming enterprise for a farm which was operating with inefficiencies to start with, and can improve production so that land demand on farm reduces by 15%. However, there is uncertainty in the costs and practicalities of some of the interventions proposed and the extent to which they are scalable. It is also worth noting that for the national policy of net zero emissions to be successful, it would not be necessary for individual farming enterprises to achieve net zero emissions, since this could be achieved and national scales by balancing land use and decarbonisation in different parts of the economy.

Conclusions

In order to avoid dangerous climate change the world needs to make deep and immediate cuts in greenhouse gas emissions at a global scale. This alone will be insufficient to achieve the target of avoiding global temperature rises above 1.5° C. In order for this to be successful there is a need to begin large-scale removals of greenhouse gases from the atmosphere within the next three decades and beyond. The agriculture and land use sectors will play a critical role in delivering this mitigation and carbon uptake, partially through improving efficiency and reducing meat demand to free up land area for sequestration activities. The UK is committed to achieving a net zero emissions of greenhouse gases by 2050. In order to achieve this it will be necessary to develop policies and undertake further research that help to deliver significant reductions in agricultural greenhouse gases alongside management interventions in the land use sector to remove atmospheric CO_2.

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