# Pathways to climate neutral farming systems

*J Herron[1], C Buckley[2], D O'Brien[3], L Shalloo[1], K Richards*

[1] Teagasc, Animal & Grassland, Research and Innovation Centre, Moorepark, Fermoy, Co. Cork,

[2] Teagasc, Rural Economy Research Centre, Athenry, Co. Galway,

[3] Teagasc, Environment Research Centre, Johnstown Castle, Co. Wexford, [4]Teagasc Climate Centre

## 1. Introduction

The EU's sustainable growth policy, the Green Deal, aims to curb climate change by cutting greenhouse gas (GHG) emissions and enhancing carbon removals. Ireland is supporting the EU Green Deal through implementing the Climate Action Plan mandated in the Climate Action and Low Carbon Development Bill 2021. The Bill legally commits the nation to a 51% reduction in GHG emissions by 2030 relative to 2018 levels, and requires the state to reach climate neutrality by 2050. Climate neutrality in an Irish context means a sustainable economy where GHG emissions are balanced or exceeded by the removal of GHGs.

Achieving the ambitious national targets requires concerted action from all sectors of the economy, including agriculture. In contrast to most European nations, agriculture accounts for a major share (35%-40%) of Ireland's GHG emissions (Duffy et al., 2023). This is in part because Irish agriculture is comprised mainly of pasture-based ruminant livestock systems i.e. beef, dairy and sheep farms. It is also caused by the lack of heavy industries in Ireland, which tend to dilute agriculture related emissions in industrialised nations. Last year, Teagasc re-examined the capacity to mitigate agricultural GHG emissions using a marginal abatement potential curve (MACC). The third version of the Teagasc GHG MACC showed the sector can meet the 2030 climate commitments by widely adopting existing mitigation practices, and by developing and implementing new technologies e.g., feed additives (Lanigan et al., 2023). Post 2030, Irish farmers will need additional emission reduction and removal technologies to become climate neutral. This study seeks to develop pathways to climate neutrality for some of the Teagasc Signpost demonstration farms, namely beef, dairy, sheep and tillage farms. For these farms, climate neutrality was evaluated on a territorial basis with the Intergovernmental Panel on Climate Change (IPCC) methodology.

## 2. Pathways to farm neutrality

Before plotting a pathway to neutrality, it is important to establish the starting point to assess the size of the task across different farm systems. The Teagasc National Farm Survey (NFS) is a nationally representative sample of approximately 850 farms from across Ireland. Data from the Teagasc NFS represent the Irish component of the European Union's Farm Accountancy Data Network (FADN) dataset. However, the data collected in the Teagasc NFS surpasses the requirements of FADN, giving the Teagasc NFS dataset much more capacity to measure and track developments in agricultural sustainability. Teagasc publishes an annual sustainability report, which outlines the economic, environmental and social position across a number of farm systems. This report included GHG emission at farm scale across dairy, cattle, sheep and tillage farms using the national GHG inventory report methodology for agricultural and energy sectors. The GHG emissions profile of these farm system types is presented below in Table 1 (Buckley & Donnellan, 2023).

**Table 1:** Farm and Emissions profile by farm system type, in 2022, using Teagasc National Farm Survey

| Farm Type | Dairy | Cattle | Sheep | Tillage - Average | Tillage - No Livestock |
|---|---|---|---|---|---|
| Sample No. | 262 | 333 | 106 | 73 | 27 |
| Population Represented | 15,323 | 48,227 | 13,979 | 6,246 | 2,393 |
| UAA[1] (ha) | 64.8 | 34.8 | 45.0 | 63.9 | 78.4 |
| Total LU[2] | 134.3 | 42.7 | 50.2 | 32.1 | 0.0 |
| Gross GHG emissions (t $CO_2$-eq/ha) | 9.6 | 4.6 | 3.5 | 2.1 | 0.8 |

[1] Utilised agricultural area, [2] Livestock unit

The objective of the Teagasc MACC is to identify the most cost-effective mitigation pathway to reduce GHG emissions and enhance carbon sequestration in the Agricultural, Land-Use, Land-Use Change, Forestry and Bioenergy sectors. This is achieved by assessing the abatement potential of GHG mitigation measures and the associated costs of adoption. The Teagasc MACC is an important report for the agricultural industry as it assists stakeholders in making informed decisions on achieving targets such as climate neutrality, by providing insight into the cost effectiveness and abatement potential of mitigation measures. While the MACC report is at a sectoral level, farm level plans can be created by identifying mitigation measure appropriate for individual farms. To demonstrate how the MACC can be applied at farm level to achieve neutrality, four Teagasc Signpost demonstration farms, each representing a beef, dairy, sheep and tillage farm, were modelled from the sample of farms. The farms selected were; 1) a highly stocked progressive dairy system, 2) a suckler-to-weanling/store beef system, 3) tillage systems with and without livestock and a 4) highly stocked sheep system with high ewe prolificacy.

To determine the starting point for each system, enterprise specific life cycle assessment models developed by Teagasc (Foley et al., 2011; Farrell et al 2022; Herron et al. 2022) were populated with farm activity data collected as part of the Teagasc Signpost programme. This establishes the "Baseline", or starting point for each system. To achieve neutrality, the farms first must adopt available and emerging measures outlined in the Teagasc MACC. To establish the "Target" system, these measures were applied to the relevant system:

- **Ruminant systems**: fertiliser measures (quantity, type), feed measures (quantity, quality, source, additives), manure measures (timing, additives), and production measures (EBI, age of finishing, age at lambing).
- **Tillage systems:** straw incorporation and cover crops.

Consistent with the Teagasc NFS sustainability report and the national climate targets, the scope of this study includes emissions from the agricultural and energy sector. Emissions are presented on a per hectare basis as a proxy for total farm GHG emissions. Three GHG emissions scenarios were simulated:

1. Gross – Baseline systems simulated, and Target systems simulated with a high adoption rate for available and emerging mitigation measures. The measures adopted are tailored to the type of farming system.
2. Net - The Target systems with the inclusion of C sequestration in soils and hedgerows. All farms are on mineral soils, an average sequestration rate of 0.64 t C/ha was used (Murphy et al. 2024). Carbon sequestration rates for hedgerow were calculated using LiDar measurement of hedgerow length and the new hedgerow model (Black et al., 2023).
3. Split – Building on the Net scenario but treating short and long-life greenhouse gases separately: Biogenic methane meeting Methane Pledge (IEA, 2022) commitment (10% reduction) and long-life gases ($CO_2$, $N_2O$) balanced by removals to achieve neutrality.

**Table 2:** Greenhouse gas emissions (tonne $CO_2$-eq/ha) from selected dairy, beef, sheep and tillage farms participating in the Teagasc Signpost programme

| | System | Dairy | Cattle | Sheep | Tillage - Average | Tillage - No Livestock |
|---|---|---|---|---|---|---|
| Gross emissions | Baseline | 12.0 | 5.3 | 8.7 | 1.0 | 0.6 |
| | Target | 9.6 | 4.3 | 7.0 | 0.9 | 0.5 |
| Net emissions | Target | 7.8 | 2.5 | 5.2 | -0.1 | -0.5 |
| Split emissions | Target | 0.4 | -0.6 | 0.0 | NE[1] | NE |

[1] Not estimated

The farming systems, most notably the ruminant systems, had higher GHG emissions/ha in comparison to their respective averages in the NFS (Table 1). This was due to the selected farms having higher stocking rates and production per ha in comparison to NFS average. Being part of the Teagasc Signpost programme, all four farming systems had already adopted a number of the mitigation strategies outlined in the Teagasc MACC. However, as evident when comparing Baseline with Target scenarios further mitigation can be achieved.

Transitioning towards the Target system reduced gross GHG emissions from the dairy, beef, and sheep systems by 2.5, 1.0, and 1.7 t $CO_2$-eq/ha, respectively. However, gross GHG emissions alone do not capture the true flux of GHG emissions from agricultural systems.

When C sequestration by practices such as cover crop and straw incorporation were included in the Net scenario for the tillage system, climate neutrality was achieved. In contrast, no ruminant system achieved climate neutrality in the Net scenario despite the adoption of the current MACC mitigation measures and the addition of C sequestration through appropriate management of mineral soils and hedgerows. The removal of C on the selected Signpost farms was not sufficient to balance GHG emissions, in particular enteric methane emissions. The NFS average farms had lower gross GHG emissions per ha than the Signpost farms, and thus would have lower Net GHG emissions per ha if the same C sequestration rate was applied. However, while all Signpost farms in this analysis are managed on mineral soils, the nationally representative sample of NFS farms operate on a range of soil types, including organo-mineral or peat soils, which have been noted as source of C emissions rather than removal.

A key criticism of the IPCC's Global Warming Potential is its inability to distinguish the behaviour of short- and long-lived greenhouse gases in the atmosphere, with calls to adopt a "split" gas approach when creating GHG reduction targets (Lynch et al., 2020). In the "Split" scenario, biogenic methane emissions were reduced in line with the Global Methane Pledge, with residual long life GHG ($CO_2$ and $N_2O$) emissions needing to be balanced by carbon removal to achieve climate neutrality. By taking a split gas approach, the beef and sheep systems achieved climate neutrality. The dairy system was still a net emitter of GHG emissions albeit 0.4 t $CO_2$-eq/ha. The dairy system fell short as emissions driven by stocking rate exceeded the farm C removals implemented.

## 3. Future research needs

Improvement in the efficacy of existing mitigation measures and the development of new measures is urgently needed to reduce emissions of $CH_4$, $N_2O$ and $CO_2$ from agricultural sources, in particular:

- Development of methane reducing feed and slurry additives for incorporation into grazed grassland systems.
- Further breeding and selection of low emitting ruminants to enhance methane abatement potential.
- Research and demonstration to increase the integration of trees with agricultural systems to enhance carbon capture and other ecosystem services such as biodiversity and water quality.

The adoption rates assumed in this analysis and under Pathway 2 within the latest Teagasc MACC analysis are very ambitious. Historically change happens slowly or incrementally and not uniformly across the farming population. Additional research to elucidate what drives change around adoption across different cohorts of farms as a one size fits all policy approach is not likely to produce the desired level of adoption of mitigation measures, this will establish the barriers and enable policymakers to tailor a mix of instruments (e.g. incentives, regulation, education & extension) to enhance the uptake of mitigation measures.

Data collection will be needed to measure and verify management change at farm level on its journey to climate neutrality. Data integration will be central in this process. AgNav, a digital sustainability platform, developed by Teagasc, ICBF, and Bord Bia with the support of the Department of Agriculture Food and the Marine will provide farmers with accurate and verifiable information to support decision making on farm to help meet agriculture's climate targets (Herron et al., 2023). To achieve this, data integration is at the core of AgNav. A selection of the GHG mitigation measures in the Teagasc MACC have already been incorporated into AgNav. Over time, AgNav will have more of the mitigation measures in the Teagasc MACC, including carbon removal practices. This should better reflect the overall GHG balance at farm level and provide a tool to support carbon farming.

This analysis used an average soil C sequestration rate, however it is important to note that large uncertainties exist, with grassland soils on the dairy farm in Johnstown Castle ranging from a sink of 2.65t C/ha per year to a source of 1.88 t C/ha per year. Due to the drought in 2018, Johnstown Castle soils were observed to emit rather than sequester C, thus highlighting volatility and the need for long-term measurement. Furthermore, the farms in this analysis were all managed on mineral soils. If farms were managed or partly managed on organo-mineral or peat soils, achieving climate neutrality would be even more difficult, if not impossible, as such soils are viewed as a major source of GHG emissions under the Land-use, Land-use change and Forestry sector in the National GHG inventory.

Further research is required to improve our understanding of the factors influencing GHG emission from agricultural systems. Examples of such research are presented by Murphy et al. (2024) and Saunders et al. (2024) who highlighted the considerable research effort across Teagasc and the Universities to reduce uncertainties through the refinement of GHG emission factors and carbon sequestration rates for mineral and organic soils. This research will provide soil type specific land-use, land management and climate emission factors that can be coupled with high resolution soil maps. There is a need to provide farmers with field and farm specific soil maps that build on the existing national soil maps available for Ireland. The soil information system has mapped Irish soils at a scale of 1:250,000, but this is insufficient for field and farm specific soil mapping to underpin carbon farming. New soil maps are required, utilising more recent soil sampling and geophysical surveys of Irish soils to create a derived soil map to support carbon farming and soil health monitoring.

## 4. Conclusion

The rapid adoption of existing mitigation measures and the development of new emerging technologies is urgent to ensure the Irish agricultural sector achieves sector targets set out in the National Climate Action Plan. Accounting for C removals can partially balance agricultural GHG emissions with residual GHG emissions occurring in ruminant systems. To achieve climate neutrality further C removal will be required. When separate targets are set for biogenic methane and long life GHG emissions, nearly all systems achieved climate neutrality. Further research into soil types and factors influencing soil C sequestration is required to reduce uncertainties.

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