Carbon-Neutrality
as a horizon point for Irish Agriculture

A qualitative appraisal of potential pathways to 2050

Teagasc

Agriculture and Food Development Authority

Carbon Neutrality as a horizon point for Irish Agriculture:
a qualitative appraisal of potential pathways to 2050

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Acknowledgements

This report is the third instalment of a series of reports by Teagasc's Greenhouse Gas Working Group. In the first two reports, we focussed on agricultural and greenhouse gases at present (Schulte & Lanigan, 2011) and in the year 2020 (Schulte & Donnellan, 2012). In this third report, we assess "pathways towards carbon-neutral agriculture as a horizon point for 2050". Throughout this study, we have relied heavily on input from, and discussions with, our colleagues at various government departments and agencies, as well as a wide range of stakeholders.

We would specifically like to acknowledge our colleagues in the Department of Agriculture, Food and the Marine, the Department of Environment, Community and Local Government, the National Economic and Social Council, the Environmental Protection Agency and University College Dublin for their time, input, ideas, creativity and commitment.

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Executive Summary

Context

This study was conducted in the context of the discussions on the development of a new national climate change policy and the publication of the Heads of a Climate Action and Low-Carbon Development Bill on 26 February 2013 by the Minister for the Environment, Community and Local Government, Minister Phil Hogan, T.D. Specifically, it aims to address and provide a scientific framework for the formidable but constructive challenge posed to the agricultural industry in the final climate policy analysis report from the NESC Secretariat: "Ireland and the Climate Change Challenge - Connecting 'How Much' with 'How To'". The latter report proposes to work towards carbon-neutral agriculture as a 'horizon point' for 2050, in which agricultural emissions are fully offset by carbon-sequestration.

The current publication is the third report by the Teagasc Working Group on Greenhouse Gas Emissions. In its first report (Schulte & Lanigan, 2011), the Working Group assessed the current scientific state-of-the-art regarding the challenges, opportunities and obstacles in relation to agriculture, greenhouse gas emissions and climate change. In its second report (Schulte & Donnellan, 2012), the Working Group looked into the immediate future and assessed the technical potential for mitigation of greenhouse gases by 2020 under a Food Harvest 2020 scenario, and collated this information in a Marginal Abatement Cost Curve for Irish agriculture. This assessment was based on current 'Kyoto' greenhouse gas inventory conventions and readily available mitigation strategies and technologies.

In this current and third report, the Working Group assesses the long-term perspective for agriculture, greenhouse gases and climate change in the context of a 'post-Kyoto' policy environment. Using 2050 as a time horizon, this current assessment has a wider scope in that it includes strategies and technologies that may not yet be readily implemented in the short term, but that may become available or feasible in the period up to 2050. Therefore, the current report builds on, and does not replace, the previous two reports by the Working Group.

The longer time horizon, explored in this report, has significant implications for the methodologies used and the nature of the findings. Our previous assessment used 2020 as a time horizon: agriculture in 2020 is likely to be shaped by both agricultural and environmental policies and market forces, the broad parameters of which are already known. Contrastingly, it is difficult, if not impossible, to assign a degree of confidence or precision to quantitative projections about the likely state of Irish and global agriculture, greenhouse gases and climate change by the year 2050, as this will depend to a large extent on the decisions and actions taken by the industry, policy makers and stakeholders during the intervening time period.

Therefore, instead of projections or predictions, the current study aims to provide 'narratives' of potential pathways towards carbon neutrality as a horizon point for Irish agriculture by 2050. Findings, conclusions, and specifically any quantitative data must therefore always be interpreted within the context of this uncertainty.

What is carbon-neutrality?

The EPA and the NESC Secretariat have defined a GHG-neutral economy (or carbon-neutral economy) as one where the net greenhouse gas (GHG) emissions associated with activities within that economy's geographic area are zero. In this context, the concept of carbon-neutrality for Irish agriculture refers to a scenario in which national GHG emissions from agriculture are fully offset by carbon sequestration by grassland soils, forestry and other land use. Given the uncertainties surrounding the feasibility of achieving *full* carbon-neutrality in Irish agriculture by 2050, it is important to note that the report from the NESC Secretariat proposes carbon-neutrality as a 'horizon point' for 2050 to which agriculture can aspire.

The concept of carbon-neutrality as a horizon point marks a change from the policy conventions used heretofore to frame the discussions on agriculture and GHG emissions, which are largely focussed on the methodologies specified by National Inventory Reports and UNFCCC reporting guidelines. In these inventories, emissions of agricultural GHG's (methane, nitrous oxides, carbon dioxide) are attributed to the agricultural sector, whilst the benefits arising from agriculture in the form of carbon-sequestration and fossil fuel offsetting are attributed to other sectors of the economy. This apparent anomaly has thus far reduced the menu of options for the agricultural industry to reduce net GHG emissions while at the same time growing the industry in the context of the Food Harvest 2020 Strategy, the phasing out of EU milk quota and international food security concerns. In contrast, the concept of carbon-neutrality as a horizon point changes the emphasis from gross emissions to net emissions (i.e. the difference between gross emissions and offsetting), which opens up opportunities to grow the industry while at the same time reducing net emissions through incentivisation of offsetting mechanisms.

Objectives

The current study has three objectives:

1. To assess the *scale* of the challenge posed by carbon-neutrality as a horizon point for Irish agriculture by 2050. This is defined by the likely magnitude of agricultural GHG emissions by 2050 and the likely magnitude of offsetting through carbon-sequestration and fossil fuel displacement by 2050, in a 'business-as-usual' scenario. The difference between emissions and offsetting is referred to as the 'emissions gap';

2. To assess potential trajectories or *pathways* for the intervening time period towards closing or at least minimising this emissions gap, and thus achieving full or at least partial carbon-neutrality by 2050;
3. To appraise the *usefulness* of the concept of carbon neutrality as a horizon point for Irish agriculture, within the context of the current UNFCCC discussions on the Advanced Durban Platform, which sets the context for a post-Kyoto international agreement, to be agreed by 2015 and to be effective by 2020.

The scale of the challenge: estimates of the Emissions Gap by 2050

The FAPRI-Ireland model was used to estimate gross agricultural GHG emissions by 2050, using a set of specific assumptions on macro-economic drivers. Bearing in mind the uncertainties surrounding these assumptions, this results in a scenario that suggests that:

1. Dairy cow numbers are likely to increase following the phasing out of EU milk quota and stabilise after 2030;
2. Suckler cow numbers are likely to be reduced gradually in line with the long-term erosion of the real value of agricultural support payments;
3. In terms of total bovine stock numbers, the likely net result is a marginal increase up to *c.* 2030, followed by a stabilisation of animal numbers.

The consequences for GHG emissions over the projection period are that emissions would rise in the short to medium term, reaching about 22 Mt CO_2eq by 2030. Emissions would continue to rise beyond 2030 but at a much lower rate.

The potential for offsetting through carbon sequestration depends on four potential carbon sinks:

1. Grassland: the sequestration potential for grasslands is estimated to equate to 6.5 Mt CO_2eq per annum by 2030, rising to 6.8 Mt CO_2eq per annum by 2050. It should be noted, however, that increased weather volatility could substantially reduce this sink.
2. Cropland: for the purpose of this exercise, we assumed that the net sequestration potential of cropland is and remains zero.
3. Peatland/wetland: in collaboration with the EPA, net national emissions from peatlands / wetlands were (roughly) estimated at 2.2 Mt CO_2eq by 2050 throughout this study.
4. Forestry: both carbon sequestration in forest biomass, litter, deadwood, soils, sequestration of carbon into harvested wood products and fossil fuel replacement abatement using forest fuelwood were considered. If fossil fuel displacement by forestry by-products is excluded, the sequestration potential for forestry is estimated to equate to 2.6 Mt CO_2eq per annum by 2030, falling to 0.8 Mt CO_2eq per annum by 2050. Including fossil fuel displacement, the sequestration potential for forestry is estimated to equate to 4.2 Mt CO_2eq per annum by 2030, falling to 1.6 Mt CO_2eq per annum by 2050.

Defined by the difference between gross agricultural emissions and agricultural offsetting, the emissions gap is likely to equate to *c*. 13 Mt CO_2eq or two-thirds of total agricultural emissions by 2030. It is of concern that the emissions gap is projected to widen between 2030 and 2050, and amount to *c*. 16-17 Mt CO_2eq or 75% of total agricultural emissions by 2050. This would largely be the result of the projected decline in the offsetting potential of existing forestry during this period.

Qualitative appraisal of pathways towards carbon-neutrality by 2050

We assessed five potential pathways towards closing – or minimising – the emissions gap by 2050. These pathways are frequently discussed in the public domain. Each of these five pathways was assessed *in isolation*, in order to fully explore its potential and limitations. Therefore, each of the pathways represents an *extreme* scenario, with one singular pathway towards closing the emissions gap.

We report on the following considerations:

- *Pathway narrative*: a brief description of the pathway;
- *Pathway description*: a technical description of how the pathway closes the national emissions gap through mitigation or offsetting;
- *Pathway constraints*: constraints to full or partial implementation of the pathway;
- *Multi-criteria assessment*: contextual considerations, specifically:
    - Impact on farm profitability and the rural economy
    - Effectiveness in contributing to a reduction in global agricultural GHG emissions (i.e. consideration of carbon-leakage and food security concerns);
    - Impact on farm productivity and economic viability;
    - Impact on land requirement and competition between land uses;
    - Potential impact on other environmental indicators (note that a full environmental impact assessment is outside the scope of the current document);
    - Resilience of the pathway to climate change.
- *Summary assessment*: finally, for each pathway we derive a summary assessment of its potential to reduce the national emissions gap for agricultural GHGs.

Pathway A (increased sequestration)

This pathway focuses on the potential for increased sequestration through an acceleration in new afforestation, over and above the current afforestation rates assumed in the BAU scenario. This pathway shows considerable scope to reduce the national agricultural emissions gap by almost half, mainly through a process of accelerating new planting rates from 8,000 to 20,000 hectares per annum. Similar planting rates have been achieved in the past and hence these rates can be considered both technically and logistically feasible.

Therefore, Pathway A could be readily considered under the heading of Track 3 of the NESC Secretariat report ('Design and Implement'). However, full realisation of the offsetting potential of Pathway A requires urgent incentivisation of farm afforestation, as it is disproportionally dependent on an 'early start' to achieve higher planting rates. This may in turn require a reappraisal of the current administrative constraints on new forestry plantation under the heading of Track 1 of the NESC Secretariat report ('Strategic and Institutional'). In addition, the efficacy of Pathway A can be maximised through optimisation / targeting of species mixtures and suitable soil types. It is important to note that the efficacy of Pathway A may be reduced between now and 2050, as it is likely to ultimately result in competition for land with agriculture. In addition, Pathway A is likely to impact on other aspects of environmental sustainability and show sensitivity to climate change.

Pathway B (advanced mitigation)

In this pathway, the emissions gap is reduced through technological and farm managerial interventions and solutions. It gives a central role to science, technology and knowledge transfer (KT) and is based on reducing the carbon-intensity (carbon footprint) of agricultural produce, with the ultimate goal of reducing GHG emissions without impacting on output. The MACC report (Schulte & Donnellan, 2012) lists the efficacy and cost-effectiveness of measures delivered by a 10-year research programme. Further measures can be expected to be added to future iterations of the MACC, as new research findings become available between now and 2050.

Full realisation of the mitigation potential of Pathway B requires a comprehensive KT programme that aids farmers and advisors in customising the mitigation options for their individual farms and biophysical environment. There is significant potential to narrow the frequency distribution of carbon (and resource) efficiency between individual farms, i.e. bring the carbon-intensity of the majority of farms closer to the top 10% most efficient producers, while acknowledging constraints relating to soil types and farming system.

At this point it is impossible to predict the total mitigation potential of the suite of measures currently subject to research, or the timeframes over which new measures will come available. This is a direct result of the very nature of strategic research where outcomes are uncertain. However, given the successes to date, and given the measures that are 'close to market', Pathway B is likely to provide significant scope to reduce the emissions gap from agriculture, and thus bring the targets for the other pathways, specifically A and C, closer within reach. All measures should be carefully evaluated for cost-effectiveness. In addition and specifically in this Pathway, hard societal choices may be required between reducing greenhouse gas emissions from agriculture, and other aspects of sustainability.

Pathway C (fossil fuel displacement)

This pathway focuses on the production of bioenergy from bioenergy crops and / or anaerobic digestion (AD) of grass and slurry. This pathway is cross-sectoral in that the bioenergy produced will displace the use of fossil fuels in the energy sector. Pathway C is unlikely to close the emissions gap on its own, as this would require an area of 0.9 million hectares to be dedicated exclusively to the production of bioenergy crops and grass for AD, as well as unprecedented capital investments in the post-farm infrastructure for energy generation. However, there is a realistic potential for pathway C to contribute to the closing of the emissions gap: existing technologies continue to achieve incrementally higher conversion efficiencies.

The main obstacles to materialising the potential of Pathway C consist of economic, policy and legislative constraints, rather than technology or the availability of land. From an administrative point of view we have to consider the risk of 'double-accounting' of carbon credits with the energy sector in this pathway. If bioenergy production can be counted by the energy sector in meeting its target of full decarbonisation by 2050, then it is unclear to what extent bioenergy production can at the same time be counted as an offsetting mechanism for agriculture to close its emissions gap.

Pathway D (constrained production activity)
The 'constrained production activity' Pathway focuses on the strong correlation between bovine livestock numbers and GHG emissions. Approximately half of Ireland's agricultural GHG consist of methane emissions from enteric fermentation in bovines, which is a process that is notoriously difficult to mitigate against. Therefore, this pathway, which has been frequently discussed in the public domain, aims at a reduction in bovine livestock numbers, through either widespread extensification of production and promotion of low-intensity livestock farming systems, a significant change in livestock production systems from ruminant farming to mono-gastric production systems, and / or a reduction in food waste at household level, specifically waste of livestock produce. This pathway envisages that changes in the production of food are driven by changes in consumption patterns and consumer behaviour in response to policy incentives.

This pathway poses a major conundrum to decision makers worldwide. On the one hand, at global scale, inequities in consumption patterns of livestock produce present a major obstacle to meeting the twin challenges of food security and reducing GHG emissions, and it is increasingly acknowledged that future 'sustainable food security' requires that changes to the global patterns of both production *and* consumption of food be taken into consideration. However, our assessment also demonstrates that, when applied unilaterally to Irish agriculture, efforts to close the 'emission gap' through Pathway D alone may result in a 'worst-of-both-worlds' scenario: in the absence of a global reduction in demand for livestock produce, Pathway D is likely to increase *global* GHG emissions from agriculture and at the same time have a significant adverse economic impact on the agri-food sector.

Pathway E (residual emissions)
The 'residual emissions' pathway prioritises the objective of contributing to Sustainable Food Security at global scale over the objective of reducing national GHG emissions from agriculture *per se*, and is based on a societal acceptance that food production is inherently

associated with GHG emissions. Similar to Pathway D, Pathway E presents a conundrum for decision makers worldwide, albeit from an opposite viewpoint. In the context of meeting the twin challenges of food security and minimising agricultural GHG emissions, there is scientific and technical merit and economic justification in producing food where it can be produced most efficiently. From this perspective, Ireland is indeed well-placed to be a major global provider of sustainable, low-carbon livestock produce, and constraints on productivity and an overemphasis on reducing Ireland's national emissions could again result in the 'worst-of-both-worlds': an increase in global GHG emissions from associated with food production.

However, there are significant constraints to Pathway E if it were to be the sole pathway for agriculture towards 2050. The main risk is that it will be perceived as, or descend into, a pathway of complacency, from the perspective of both producers and consumers. This would pose risks to the current validity of the perception of Irish livestock produce as 'green' or 'sustainable', and could hence erode the value of these perceptions as a point of differentiation on international markets. In addition, Pathway E is not consistent with current international and national policies; it is predicated on some form of global governance of food production, needed to indeed produce each food product where it can be produced efficiently. In the current policy context, Pathway E will increase the proportional burden on other sectors in meeting national objectives, either in the form of emission reduction targets or carbon-neutrality targets.

Towards a mosaic of solutions

Each of the five pathways has merits and potential in reducing the emissions gap from agriculture by 2050. However, each pathway is associated with potential negative side-effects. These include potential negative impacts on global GHG emissions through carbon-leakage, adverse economic impacts on the agri-food sector, impacts on land availability or impacts on other aspects of environmental sustainability (e.g. biodiversity, water quality, societal aspects surrounding use of GMO crops). For all pathways, the magnitude of these side-effects tends to be correlated to the extent to which each pathway is pursued. In other words, the side-effects are small for the initial and partial implementation of each pathway, but increase as each pathway is pursued to its full extent. This leads us to the first conclusion:

<u>Conclusion 1: Carbon-neutrality as a 2050 horizon point for Irish agriculture must be carefully considered within the wider context of the sustainability, as negative trade-offs are likely to emerge.</u>

This suggests that it is undesirable to rely and focus on any singular pathway to reduce the emissions gap from agriculture. Discussions in the public domain are frequently dominated by the promotion and critique of such singular pathways. The outcomes of our assessment here suggest that the simultaneous pursuit and *partial* implementation of multiple pathways, is more likely to be effective in reducing the emissions gap from agriculture, while minimising potential negative side-effects. This leads us to the following conclusion:

<u>Conclusion 2: Simultaneous and partial implementation of all pathways will prove more effective and realistic than reliance on a single pathway.</u>

As the emissions gap is incrementally closed between now and 2050, it will become progressively more difficult to find further solutions and gains in efficiency, in that the 'low-hanging fruit' is likely to be picked first, unless revolutionary scientific breakthroughs change the fundamentals of livestock production. This means that it may prove difficult (or even counterproductive) to achieve *full* carbon-neutrality by 2050. Notwithstanding the uncertainties surrounding the policy and economic landscapes between now and 2050, an 'early start' on the pathway towards carbon neutrality will be required, specifically in relation to Pathway A, which relies on carbon-sequestration over a period of decades.

Unless scope can be created across the policy landscape to facilitate higher levels of forestry sequestration, then the prospect of a carbon neutral agricultural sector in 2050 is at risk. There is still a limited time window in which to create an appropriate environment to produce a substantial forestry sink in the period to 2050. However, without immediate action in respect of the forestry constraints set out in this report, then that opportunity will be lost. It will then become necessary to seriously examine an alternative 2050 ambition for agriculture.

However, such discussions on whether or not full neutrality can be achieved by 2050 should not distract from efforts to minimise the emissions gap, and to approach carbon-neutrality as a horizon point. This leads us to the following conclusion:

<u>Conclusion 3: Full carbon-neutrality for agriculture by 2050 may be difficult to achieve, but this should not distract from efforts to approach carbon-neutrality as a horizon point.</u>

Implications and recommendations

Following the conclusions above, we arrive at the following implications and recommendations, which we have framed in accordance with the three 'tracks' proposed by the NESC Secretariat (2013):

Track 3 ('Design and implement'): The efficacy of *modi operandi* of Pathways A and B have been well established: these pathways are therefore ready for implementation.

- Specifically for Pathway A, an 'early start' is essential to maximise its effectiveness, as the carbon offsetting potential of accelerated afforestration by 2050 is disproportionally dependent on the year in which planting rates were first accelerated.

- To aid and begin the implementation of Pathway B, Teagasc and Bord Bia have developed, and are currently deploying, the Farm Carbon Navigator.

Track 2 ('Explore and experiment'): This track is of specific relevance to Pathways B and C:

- For Pathway B to achieve its full potential, it relies on a 'conveyor-belt' of research and KT. Whilst the Teagasc MACC and the Teagasc – Bord Bia Farm Carbon Navigator summarises research on cost-effective GHG mitigation measures to date, further advances in reducing the carbon-footprint of agricultural produce rely on continuous investment in and support for research and KT in Pathway B.
- The implementation of Pathway C is currently in its infancy. Pathway C could be implemented in various different forms. Therefore the 'explore and experiment' track appears to be the appropriate approach to implementation of Pathway C, before deciding on the optimal model of operation.

Track 1 ('Strategic and Institutional'): This track is relevant for all Pathways. Specifically, Pathways A, B and C require national interventions at strategic and institutional level, whereas Pathways D and E require international interventions:

- The implementation of Pathway A (and C) may have implications for land use, which requires a cross-sectoral and cross-enterprise response in terms of the strategic planning of incentivisation mechanisms.
- Implementation of Pathway B requires not only continued support for research and KT on the mitigation of agricultural GHGs, but may also require a broadening of KT programmes to include all farm advisory services, i.e. including those in the private sector. This is in line with the recommendations by the Environmental Analysis of Food Harvest 2020 (Farrelly *et al*., 2013), and may have institutional implications e.g. for Teagasc itself.
- Implementation of Pathway C requires cross-sectoral policy interventions.
- Implementation of Pathways D and E requires coherent international policy interventions on the subjects of international governance of both food production and consumption. Over the last number of years, Ireland has significantly 'punched above its weight' in the international debate on food security and climate change, and is well placed to continue assuming a leadership role in these discussions.

This three-track approach brings us to our fourth conclusion:

<u>Conclusion 4: A reduction in the agricultural 'emissions gap' by 2050 requires significant and immediate incentivisation programmes, which in turn require cross-sectoral and coherent policy initiatives, both at national and international level.</u>

How useful is the concept of carbon-neutrality as a horizon point?

In this report, we used the concept and framework of ‘carbon neutrality’, as defined by the NESC secretariat: this approach towards the accounting and mitigation of agricultural GHG emissions marks a departure from previous approaches which focuses exclusively on reducing agricultural GHG emissions, without accounting for potential offsetting mechanisms. In our previous report, in which we produced a MACC for Irish agriculture, we showed that the options to reduce agricultural GHG emissions by 2020 were limited to maintaining agricultural emissions at current levels while growing agricultural outputs.

The concept of carbon-neutrality allows the agricultural sector to widen its horizons and to consider offsetting mechanisms such as carbon sequestration and fossil fuel displacement into its menu of options to reduce the impact of agriculture and land use on global GHG emissions. Our current report shows that this allows a significant expansion in the potential and positive contribution that agriculture can make. Put differently, in the context of our Pathway assessment: under the previous approach (‘reducing agricultural emissions’) agriculture could only resort to two pathways, i.e. Pathways B and D. Under the new approach (‘carbon neutrality’), Pathways A and C can be added to the mix, both of which have significant potential to reduce national GHG emissions. It also allows Pathway E to be considered in the context of finding global solutions to the twin challenges of food security and combating climate change. This leads to our last conclusion:

<u>Conclusion 5: Carbon-neutrality for agriculture as a concept and a horizon point for 2050 radically diversifies the menu of options for agriculture to make a meaningful and proactive contribution to reducing national GHG emissions.</u>

Finally, a number of aspects of the concept of carbon-neutrality as a horizon point need further clarification or exploration. These include: definition of system boundaries, cross-sectoral greenhouse gas accounting methodologies and the assessment of carbon-neutrality at supra-national level in a post-Kyoto policy framework.

Glossary

AD	Anaerobic Digestion
AR	Post-1990 afforestation
BAU	Business As Usual (in scenario analyses)
C	Carbon
CH_4	Methane
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
CARBWARE	The Irish carbon reporting system (for forestry)
COFORD	Programme of Competitive Forest Research for Development
DAFM	Department of Agriculture, Food and the Marine
DECLG	Department of Environment, Community and Local Government
DM	Dry Matter
DNDC	DeNitrification DeComposition Model
DOC	Dissolved Organic Carbon
EBI	Economic Breeding Index
EPA	Environmental Protection Agency (Ireland)
ETS	Emissions Trading Scheme
EU	European Union
FACCE-JPI	EU Joint Programming Initiative on Agriculture, Food Security and Climate Change
FAO	Food and Agriculture Organisation
FAPRI	Food and Agricultural Policy Research Institute
FM	Pre-1990 forests
FP7	Seventh EU Framework Programme
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GJ	Gigajoule
GMO	Genetically Modified Organism
GPP	Gross Primary Productivity
GRA	Global Research Alliance
HWP	Harvestable Wood Product
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre of the European Commission
KT	Knowledge Transfer
kWe	Kilowatt equivalent
LCA	Life Cycle Assessment
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal Abatement Cost Curve
Mt	Megaton
MWh	Megawatt-hour
N	Nitrogen

N_2	Di-nitrogen
N_2O	Nitrous Oxide
NBP	Net Biome Productivity
NESC	National Economic and Social Council
NEP	Net Ecosystem Productivity
NIR	National Inventory Report
NFI	National Forest Inventory
Non-ETS	Sectors outside the Emissions Trading Scheme
ppm	Parts per million
QA	Quality Assurance
R&D	Research and Development
Ra	Autotrophic respiration
RDS	Royal Dublin Society
Rh	Heterotrophic respiration
SEAI	Sustainable Energy Authority of Ireland
SFI	Science Foundation Ireland
SOC	Soil Organic Carbon
SSP	Shared Socio-economic Pathway
t	Tonne (metric)
TIMES	(Irish) Energy System Model
TMR	Total Mixed Ration
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Carbon
WHO	World Health Organisation

Table of Contents

1. Introduction

In this section we provide a context for this report. We summarise earlier contributions by Teagasc which have helped shape this submission. Key questions that arise in light of the report of the Secretariat of the National Economic and Social Council (NESC) are identified. Finally, the scope of the assessment to be undertaken is specified in the terms of reference for the study.

1.1 Context

1.1.1 National Climate Change Policy

In this report, Teagasc presents a qualitative appraisal of potential pathways towards carbon-neutral agriculture by 2050. This report is the result of a six-month study that was undertaken in the context of the discussions on the development of a new national climate change policy and the publication of the Heads of a Climate Action and Low-Carbon Development Bill on 26 February 2013 by the Minister for the Environment, Community and Local Government, Minister Phil Hogan, T.D. Specifically, we aim to address and provide a scientific framework for the formidable but constructive challenge posed to the agricultural industry in the final climate policy analysis report from the NESC Secretariat: *Ireland and the Climate Change Challenge - Connecting 'How Much' with 'How To'*. The latter report proposes to work towards carbon-neutral agriculture as a 'horizon point' for 2050, in which agricultural emissions are fully offset by carbon-sequestration (NESC Secretariat, 2013).

1.1.2 Previous submissions and publications by Teagasc

This report is the most recent in a series of three reports on Irish agriculture, climate change and greenhouse gas emissions, published by Teagasc's Working Group on Greenhouse Gas Emissions.

In our first report, 'Irish Agriculture, Greenhouse Gas Emissions and Climate Change – opportunities, obstacles and proposed solutions' (Schulte & Lanigan, 2011), we highlighted the *difficulties* associated with reducing agricultural greenhouse gas emissions, specifically:

- The need to consider agricultural greenhouse gas emissions in the context of the twin challenge of global food security in the face of a projected growth of the world population and associated demand for food. In this context, Irish livestock production systems are among the most carbon-efficient systems in the world, when expressed on the basis of greenhouse gas emissions per unit produce;
- Ireland's unusual national greenhouse gas emissions profile, in which agriculture accounts for a large share of national emissions. We explained that this profile should not be interpreted as evidence of low levels of carbon-efficiency in Irish agriculture. Instead, this profile is largely a reflection of the importance of the agricultural sector to the national

economy, with 80-90% of agricultural produce exported to consumers abroad, as well as the absence of large scale manufacturing industry, which 'masks' agricultural emissions in many other jurisdictions;

- The risks of carbon-leakage, if implementation of absolute territory-based emissions targets for Irish agriculture were to result in a displacement of livestock production to less efficient regions of the world;
- Most importantly, the difficulties in the accountancy of potential further improvements in agricultural efficiencies and carbon-offsetting in the National Greenhouse Gas Inventories required by the UNFCCC process, specifically:
    - The territorial boundaries of the National Greenhouse Gas Inventories account for only those emissions originating within national boundaries. In some cases, this may lead to incentivisation of 'perverse' mitigation measures that reduce national emissions but increase global emissions;
    - Within the National Greenhouse Gas Inventories, agricultural emissions are reported separately from the Land Use, Land Use Change and Forestry Sector. As a result, the Inventories attribute nitrous oxide and methane emissions from livestock farming to the agricultural sector, whilst the carbon sequestration from e.g. forestry is allocated to the LULUCF sector.

For full details see Schulte & Lanigan (2011).

In our second report, 'A Marginal Abatement Cost Curve for Irish Agriculture' (Schulte & Donnellan, 2012), we reversed the question and assessed the scope for potential GHG emission reductions from Irish agriculture by 2020, against a background of the Food Harvest 2020 strategy. Food Harvest 2020 is the Industry-led vision, supported by government, for the expansion of the agriculture-food industry up to 2020, following the phasing-out of EU milk quota by 2015. In setting growth targets for the agricultural industry, this strategy contains, *inter alia,* a 50% increase in milk volume and a 20% increase in the value of beef.

This second report was written in the context of the National Climate Policy Consultation and the interim report by NESC (2012). We produced a marginal abatement cost curve (MACC) for Irish agriculture, effectively producing a menu of abatement options ranked in order of their cost-effectiveness. Using 2020 as a time horizon, we employed and contrasted two methods to calculate the abatement potential of individual measures, i.e. the Life Cycle Assessment (LCA) methodology and the methodology used in the National Emission Inventories (IPCC methodology). The main outcomes of this study were:

- The projected growth of the agricultural sector is likely to increase total agricultural emissions by 7% by 2020, in the absence of additional mitigation measures.
- Using the LCA methodology, there is the biophysical potential to reduce emissions from agriculture by 2.5 Mt carbon-dioxide equivalents (CO_2eq). However, only 1.1 Mt of this annual mitigation potential can be accounted for in the current National Emission Inventory;

- The cultivation of biofuel / bioenergy crops has potential to account for a further reported annual reduction of 1.2 Mt of CO_2eq per annum by 2020, mainly associated with the displacement of fossil fuel usage. However, in the Irish National Emissions Inventory, these energy related reductions would largely be attributed to the fuel consuming sectors defined in the IPCC methodology, i.e. the transport sector and power generation sector;
- The 1.1 Mt potential annual reduction that can be accounted for in the National Emissions Inventory would reduce total annual emissions from agriculture to 18.9 Mt CO_2eq. In relative terms, this 2020 emission level corresponds to:
    - 5.5% reduction in emissions compared to the default (without measures) Food Harvest 2020 reference scenario;
    - No change compared to the emissions during the first Kyoto commitment period (2010-2012);
    - 4.5% reduction in emissions compared to 2005, i.e. the EU Effort Sharing reference year;
- In terms of cost-effectiveness, the mitigation measures were ranked in the order of efficiency > bioenergy/biofuel > technology. Measures aimed at improving farm efficiency were most cost-effective in terms of reducing greenhouse gas emissions, as these measures increase the output:input ratio of agriculture. Most measures that involved the production of bioenergy/biofuel were cost-neutral, whilst most technological interventions were cost-prohibitive, i.e. were associated with relative abatement costs in excess of the international purchase price of carbon-credits.
- Further reductions in agricultural emissions, over and above the cost-effective reductions identified in the MACC, will require either:
    - The introduction of mechanisms to incentivise the cultivation of biofuel / bioenergy crops;
    - The introduction of mechanisms to incentivise farm forestry;
    - Financial incentivisation of measures that are currently cost-prohibitive;
    - The future introduction of additional mitigation options that are currently the subject of ongoing research.

For full details, see Schulte & Donnellan (2012).

Since the publication of the MACC, Teagasc and Bord Bia have jointly developed the Teagasc-Bord Bia Farm Carbon Navigator. The Farm Carbon Navigator is an advisory tool aimed at assisting farmers in implementing cost-effective mitigation measures on their farm. The Navigator is currently being implemented as part of the Beef Technology Adoption Programmes and Dairy Discussion Groups. The Farm Carbon-Navigator will be discussed in-depth in Section 4.3.3 of this report; for full details, see Murphy (2012).

1.1.3 The new challenge: towards carbon-neutral agriculture by 2050?

In its final report *Ireland and the Climate Change Challenge - Connecting 'How Much' with 'How To'* (NESC, 2013), the NESC Secretariat recognised the difficulties associated with developing greenhouse gas abatement strategies for agriculture that can be accounted for under the 'Kyoto' inventories. Summarised by the phrase 'thinking for ourselves', it proposes a radically new target for Irish agriculture: carbon-neutrality as a 2050 horizon point, in which emissions are offset by carbon sequestration in grassland, forestry and other land use, as first proposed by O'Reilly *et al*. (2012). We cite:

"(…) A central thrust of our work on this project has been to reframe the way in which agriculture is considered within, and relates to, the climate-change agenda. Ireland needs to, and can, become a world leader in the production, management and marketing of low-carbon, high-quality sustainable food. This can be achieved by adopting carbon neutrality as a point on the horizon for the country and the industry to work towards. The challenge of working towards carbon neutrality will be achieved by pushing scientific research and probing practice to identify further means of reducing emissions and ways of maximising the carbon-sink potential associated with land use, land-use change and forestry (…)" (NESC Secretariat, 2013).

This new approach signals a significant change in contemporary thinking, and has the potential to overcome many of the methodological difficulties in reducing reportable agricultural greenhouse gas emissions, identified in our first and second reports (Schulte & Lanigan, 2011; Schulte & Donnellan, 2012) (see Section 1.1.2).

- Firstly, and most importantly, this approach allows the carbon sequestration potential of grassland, biofuels / bioenergy and forestry to be considered as mitigation options within the agricultural sector, thus providing potential incentivisation mechanisms for carbon offsetting.
- Secondly, the approach changes the policy objective from an exclusive focus on a reduction in the absolute emissions from agriculture towards a solution involving emissions abatement and carbon sequestration. In principle, this approach allows for growth of the agricultural industry and associated emissions – as long as this takes place in tandem with enhanced offsetting through sequestration. This means that the concept allows for the computation of both the carbon-intensity of agricultural produce, and absolute annual emissions balance.
- Finally, the approach has the potential to take away some of the abstract benchmarking associated with the accountancy of agricultural greenhouse gases, as the new approach focuses on the sum of gross emissions and gross sequestration, instead of the marginal net change in emissions / offsetting measures against a specific reference year (e.g. 1990 for the IPCC inventory; 2005 for the EU Effort Sharing Agreement).

1.2 Objective

The new approach and targets proposed by the NESC Secretariat report also raise a completely new set of questions for the agricultural industry, that require detailed investigation. For example:

- How realistic or achievable is carbon-neutrality as a horizon-point for Irish agriculture, which is largely characterised by ruminant farming?
- To what extent do carbon sequestration by grasslands and forestry currently offset agricultural emissions of nitrous oxide and methane?
- Is it possible to increase this offsetting potential? At the same time, can further gains in farm efficiency reduce emissions of nitrous oxide and methane, thus reducing the need for further gains in offsetting?
- What are the potential side-effects (in both economic and environmental terms) of actions aimed at further increases in efficiency and offsetting?

To answer some of these questions, we report here on the most recent work of Teagasc's Working Group on Greenhouse Gas Emissions, which has conducted a qualitative appraisal of 'potential pathways towards carbon-neutrality'. The objectives of this study were to:

1. Explore the extent to which agricultural GHG emissions can be offset by carbon-sequestration in 2050;
2. Establish the subsequent 'emissions gap', i.e. the gap between GHG emissions and offsetting that needs to be 'closed' in order to achieve carbon-neutrality by 2050;
3. Explore the potential and obstacles of contrasting pathways aimed at closing this emissions gap by 2050.

This appraisal applies to potential trajectories of Irish agriculture towards the year 2050. It should be emphasised that this assessment is additional to, and does not replace, our framework for mitigation agricultural emissions by the year 2020, as articulated in the MACC (Schulte & Donnellan, 2012). This means that while Teagasc is proactively developing and implementing tools that will assist in the adoption of the mitigation measures identified in the MACC, we simultaneously look ahead at the next target of carbon-neutrality by 2050. In the context of the recommendations of the NESC Secretariat:

- The measures identified in the MACC fall within 'Track 3: Design and Implement'
- The potential pathways towards carbon-neutrality discussed in this current report fall within 'Track 2: Explore and Experiment'.
- The lessons that will be learnt throughout this process will be of direct relevance to 'Track 1: Strategic and Institutional'.

1.3 Terms of reference

It is important to emphasise that the approach used in our assessment of pathways towards 2050 differs fundamentally from the approach we used in the development of the MACC in our previous report. Whereas we employed economic and biophysical models to generate the MACC for 2020, our current assessment for 2050 is largely based on a qualitative *ex-ante* appraisal.

The main purpose of this appraisal is to highlight and discuss the '*pros*' and 'cons', or opportunities and obstacles, of contrasting approaches towards carbon-neutrality. These pros and cons are mostly generic in that their nature does not depend on the exact quantitative projections on the development of the agricultural industry in Ireland.

Whilst quantitative models could – in principle – provide projections of scenarios for 2050, such projections could inadvertently suggest a degree of certainty or accuracy that cannot be substantiated. The main reason for this is the high likelihood that a range of undeterminable issues such as future agricultural policy, future trade policy or other market factors will influence the future outcome. Such factors can only be accounted for in today's economic models by making specific assumptions. Such factors will prove to be decisive in shaping the agricultural 'landscape' in the period to 2050. To put the difficulty of this task in context, a comparable challenge would have been to accurately predict the present status of the agri-food industry in Ireland, across the EU or globally at the time when Ireland joined the European Community in 1973.

Equally, in terms of mitigation and offsetting potential, there is a high likelihood that the period to 2050 will see significant breakthroughs in research and development. Since research by definition involves investigating the unknown, it is at this point impossible to accurately forecast the total mitigation and offsetting potential using a fully quantitative framework.

Taking these constraints into consideration, our study should be interpreted as a narrative, rather than a forecast, on pathways towards carbon-neutral agriculture from 2013 to 2050.

2. Approach and methodology

In this section we define carbon neutrality, the likely drivers of change in agriculture over the next 30 to 40 years and we posit a number of scenarios which reflect how the apparent conflict between food security and the impact of agriculture on climate change could evolve.

2.1 Principles of carbon-neutral agriculture

2.1.1 What is carbon-neutral agriculture?

The EPA has defined a GHG-neutral economy (or: carbon-neutral economy) as one where the net greenhouse gas emissions associated with activity within that economy's geographic area are zero (O'Reilly *et al*., 2012). In this context, the concept of carbon-neutrality for Irish agriculture refers to a scenario in which national GHG emissions from agriculture (CH_4, N_2O, CO_2) are fully offset by C-sequestration by grassland soils, forestry and other land use. Given the uncertainties surrounding the feasibility of achieving *full* carbon-neutrality in Irish agriculture by 2050, it is important to note that the report from the NESC Secretariat proposes carbon-neutrality as a 'horizon point' for 2050 to which agriculture can aspire.

2.1.2 Previous estimates of the emissions gap

Current national GHG emissions from Irish agriculture (2008-2012 first Kyoto commitment period) amount to 18.8 Mt CO_2eq per year. In our second report (Schulte & Donnellan, 2012), we projected that emissions were likely to increase to 20.0 Mt CO_2eq per year by 2020 under a Food Harvest 2020 scenario in the absence of additional abatement measures ('without additional measures scenario'), or to stabilise at 18.9 Mt CO_2eq per year by 2020 under a Food Harvest 2020 scenario in which all cost-beneficial, cost-neutral and cost-effective measures of our MACC are fully implemented ('with additional measures scenario'). In Section 2.3 of the current report we provide a first assessment of agricultural GHG emissions in the period to 2050, emphasising the considerable uncertainties around such a projection.

The EPA (O'Reilly *et al*., 2012), based on a study by Byrne *et al*. (2007), estimated the total current offsetting potential of land use in Ireland at 6.3 Mt CO_2eq per year. It identifies grassland and forestry as two major sinks and degraded wetlands/peatlands and as a major source, with cropland considered to be carbon-neutral. The EPA study projects that there is scope to increase this net offsetting capacity to 8.9 Mt CO_2eq per year by 2050. These projections suggest that a significant difference between agricultural emissions and offsetting is likely to remain. It proposes a reduction target of 50% for agricultural emissions by 2050 to minimise this emissions gap and concludes that "To achieve targets without international purchases could be very costly and would most likely require a step-up in ambition from the agricultural sector".

2.1.3 Embedded emissions

In the description of carbon-neutrality, O'Reilly *et al*. (2012) point out that "the IPCC [Intergovernmental Panel on Climate Change] reporting guidelines address emissions within a nation's boundaries only, and that 'embedded emissions' in imported products are not included." They subsequently define 'embedded emissions' of products as "those emissions released in the production of the good, including processing emissions, emissions from the production of inputs, associated direct and indirect land-use change etc."

In our first report (Schulte & Lanigan, 2011) we explained how ignoring embedded emissions in the framing of climate change mitigation policies has the potential to result in incentivisation of 'perverse' mitigation measures, i.e. measures that reduce GHG emissions within national boundaries, but simultaneously increase global emissions. This situation arises where locally produced inputs (e.g. feedstocks grown within national boundaries) are replaced by imports with a higher carbon-intensity. Within the concept of a national GHG balance, this situation will replace 'national emissions' with 'embedded emissions'. Since the latter emissions are not accounted for in the carbon-balance, this will result in lower 'national' but higher global emissions.

Acknowledging the potential drawbacks of excluding 'embedded emissions', O'Reilly *et al*. (2012) conclude that "sustainability models may include efforts to identify and reduce embedded emissions". However, in this first iteration of our assessment of carbon neutrality, the scope of our appraisal of pathways in this report focuses in the first instance on national emissions, for reasons explained in Section 5.2.2. The potential impacts on carbon-leakage and global emissions are discussed as contextual constraints for each pathway.

2.2 Drivers of change

Irish agriculture is largely export based, with the principal livestock sectors exporting up to 85-90% of produce. As a result, it is sensitive to international policy and market drivers. These drivers are likely to play a dominant role in shaping the future of the agricultural industry, both in terms of output and in terms of carbon intensity. Therefore, it is important that we consider our appraisal of national pathways towards carbon-neutral agriculture within the context of these international drivers.

Globally, the two main challenges for agriculture are food security in the context of a growing world population and the mitigation of and adaptation to climate change.

2.2.1 Food security

The FAO (Alexandratos & Bruinsma, 2012) projects that global demand for food will increase by 60% in the period 2005-2050, reflecting a growing world population and changes in dietary preferences (i.e. increased consumption of animal protein), specifically in emerging economies. This projected increase in demand has spurred international activity in the field of agricultural research, extension and development, with a view to raising the production of food by similar levels. However, recent thinking on food security has evolved to stress the importance of universal access to food over and above the global demand for food (JRC expert workshop on sustainable food security, Seville, 8-9 April 2013). This universal access to food is currently impeded by numerous institutional and socio-economic barriers, resulting in about 1 billion of the world's population being undernourished. The global effort to ensure food security in the context of access to food involves more than agricultural research, extension and development. Whilst these latter disciplines have a clear role to play in increasing the productivity of global agriculture, new issues on food security are emerging that require an interdisciplinary approach. These include:

- the unequal distribution of food, both geographically and within societies, resulting in the simultaneous challenges of undernutrition and overnutrition;
- high levels of food losses and food waste, either at production or distribution level (mostly developing countries) or consumer level (mostly developed countries (Lipinski *et al.*, 2013);
- the implications of dietary preferences in developed and emerging economies in terms of sustainability and impacts on global greenhouse gas emissions from agriculture (Bellarby *et al*., 2013);

It is important to emphasise that the proportion of income that consumers in developing countries spend on food is far higher than in developed countries. In the developing world households very often consume relatively unprocessed products. Often 40% or more of household income can go on food. By contrast in Ireland the average household spends about 16% of its income on food, much of it in a processed form. Ultimately, this means that the impact of rising food prices impacts quickly and more sharply on households in the developing world. Many of these challenges fall outside the scope of this report, but see Sonnino & Moragues-Faus (2013) for a full review.

Notwithstanding the complexity of the global approaches required to achieve food security, increased agricultural productivity will be an essential ingredient of the interdisciplinary suite of solutions. At the global level, the environmental sustainability of this increased productivity is likely to be higher if:

- the productivity increase is achieved through increased productivity on the current global agricultural area, rather than from an expansion of the agricultural area, as discussed in our first report (Schulte & Lanigan, 2011);
- resource use efficiency is maximised by the cultivation of food products in their optimum environments (e.g. Haygarth & Ritz, 2009; Benton, 2012; Fresco, 2012; Schulte *et al*., 2013). Put simply: in general, growing each crop / livestock type where it grows best ('global trade') is environmentally more efficient than growing all crops / livestock types locally ('national self-sufficiency'). However, see Section 4.6.2 for a more nuanced analysis.

We will discuss the implications of this in further detail in section 4.6.

2.2.2 Climate change
Climate change is the second driver of the future development of the agricultural industry, both in terms of mitigation of greenhouse gases, and adaptation to climate change itself. Agriculture will mainly be impacted upon through increased frequency of extreme events (e.g. droughts, floods), rather than changes in temperature or rainfall *per* se (IPCC, 2007). At the same time, the IPCC fourth assessment report suggests that the global pathway of economic and technological development (see section 2.2.1) will have a larger impact on Food Security than climate change itself.

As discussed in our first report (Schulte & Lanigan, 2011), the medium-term effects of climate change on the Irish climate are predicted to be much less severe than effects on the climate in continental Europe and worldwide in general, with contrasting resultant implications for agriculture. Parry *et al*. (2004) ran simulations using four IPCC climate scenarios (IPCC, 2007) and projected that while agricultural productivity was severely reduced in South America and Africa due to climate change, effects were less pronounced in parts of North America and North-western Europe, including Ireland.

Weighted downscaling from Global Climate Models suggests a 10% increase in winter rainfall in Ireland by 2050, rising to up to 17% by 2080 (Sweeney, 2008), which may have implication for the total abatement potential of extended grazing, an important cost-beneficial measures identified in our MACC report. At the same time, summer water deficits of up to 17% are projected occur by 2050, rising to between 14-25% by 2080. The largest summer deficits are projected for the southern and eastern coasts (20% by 2050, increasing to 30–40% by the 2080s). The impacts on agricultural production are projected to be regionalised with improved yields in the West and North-West of Ireland by the 2050s and little impact in the South-West which is predominantly focussed on dairy farming. However, the South-East of the country is projected to experience severe summer droughts with a reduction in grass and barley yields (Holden & Brereton, 2002; Holden *et al*., 2003; Sweeney, 2008). In addition, shifts from fungal to insect pests of crops and animal are likely to occur (Olesen & Bindi, 2002).

Climate change will not only impact on primary production, but also on the effectiveness of climate change mitigation measures and indeed offsetting mechanisms. This has the potential to result in positive (i.e. undesirable) feedback loops, in which the attempts to curtail GHG emissions are affected by climate change itself. The concept of carbon-neutral agriculture relies heavily on carbon sequestration by forestry and grassland for the offsetting of N_2O and CH_4. In our first report (Schulte & Lanigan, 2011), we described the potential impact of climate change on forestry:

"Changes in the timing of spring bud burst may result in trees being more susceptible to late spring frost. Changes in productivity, and species composition, can also be expected as moisture and temperature conditions are key factors affecting productivity, with reduced productivity likely in areas that will become drier. Tree species selection and potential productivity gains may not be realized if genotypes are not selected to suit future climates. As a higher percentage of the forests in Ireland will be in younger age classes, species that are not well adapted to climate change will be particularly vulnerable. Changes in annual heat sums suggest the potential use of more southerly provenances of Sitka spruce which can take advantage of a longer growing season."

Rates of carbon sequestration in grassland are equally dependent on climate change. On the one hand, the current high rates of carbon sequestration in grassland may be a negative feedback response to the elevated CO_2 concentrations in the atmosphere (Abdalla *et al*. 2013). Put colloquially: grassland soils are sequestering carbon in an attempt to reach a new equilibrium with higher CO_2 levels in the air. On the other hand, it is likely that further increases in extreme weather events, specifically droughts, may reduce the sequestration capacity of grassland soils, as evidenced across Europe during the extreme summer of 2003, when many grassland soils temporarily turned from carbon sinks into carbon sources (Ciais *et al*., 2005; Reichstein *et al*., 2006).

2.3 Global scenarios

A number of international initiatives have explored, in the form of scenario analyses, how the two global drivers, food security and climate change, may interact with each other. These scenario analyses form the global context in which we have framed our own national appraisal of potential pathways towards carbon-neutral agriculture. In this section, we review three sets of scenarios:

1. The scenarios developed and used by the Intergovernmental Panel on Climate Change (IPCC): these describe potential combinations of economic, demographic and technological drivers across all sectors of the global society. The resulting scenarios are used to project contrasting trajectories of greenhouse gas emissions up to the year 2100.
2. The scenarios developed by the Joint Research Centre of the European Commission (JRC): these describe four potential combinations of sustainability and food security, and are used to identify the drivers and obstacles for the normative (desired) scenario of 'sustainable food security'.
3. The 'storylines' developed by the FP7 project 'Animal Change': these scenarios consist of three shared socio-economic pathways (SSP's) which enable coverage of a large share of plausible future developments. Quantitative parameters with respect to population, gross domestic product, crop yield growth, feed conversion efficiencies, and human diets are included in these storylines.

2.3.1 IPCC scenarios

Since its establishment in 1988 the IPCC has developed and used scenarios in respect of future greenhouse emissions and the ultimate impact on our climate. These scenarios are an assessment of the future impact of human activity on the climate based on current scientific, socio-economic and technical knowledge. Possible options for adapting to these consequences or mitigating the effects are also considered. The results of these scenarios are published in a series of assessment reports. Since 1990 four such assessment reports have been completed, the most recent report known as the Fourth Assessment Report (AR4) was released in 2007, while the Fifth Assessment Report (AR5) is well advanced and is expected in 2014. The first element of AR5, the Working Group 1 summary for policy makers was made available in September 2013.

In the assessment reports a suite of scenarios is set out in order to project a range of future climate outcomes. The first generation of these scenarios was the IS92 and was superseded by a second generation of scenarios known as SRES scenarios (Special Assessment Report on Emissions Scenarios). These scenarios are baseline or reference scenarios, which means that they exclude current and future measures to limit greenhouse gas emissions.

SRES scenarios make allowance for the fact that climate change will be dependent on aspects of future human activity which are as yet unknown. The uncertainties about human behaviour include global and regional population growth, economic growth, changes in technology and in productivity and political and social developments. All of these factors have future paths which cannot be known with certainty and which cannot be modelled to the same degree of certainty as a natural science process. Thus these factors will impact on the future outcome which climate models project. To take these factors into account the SRES scenarios were designed and were grouped into categories known as families. Due to the highly detailed nature of the SRES scenarios, it is not possible to summarise them here. Further detail can be found at https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

As with earlier assessment reports, AR5 has been developed through a scoping process which synthesises the knowledge of climate change experts from a range of disciplines. In AR5, SRES scenarios have been replaced by a third generation of scenarios, the so called Representative Concentration Pathways (RCPs).

Like the SRES scenarios, RCPs provide a common scenario base off which modellers around the world can align, validate and compare their research. In all there are four RCPS which are constructed to include a range of metrics, including forcing, emissions rates and emissions concentrations. Each pathway has two key values for 2100 representing the extent to which the planet has heated up and the level of concentration of greenhouse gases.

Each RCP is developed by a modelling teams based on a review of the literature that allows the selection of values for a wide range of scientific and socioeconomic variables, including population growth, economic growth, air pollution, land use and energy sources. The move from the SRES scenarios towards RCPs was motivated to allow for greater flexibility in terms of assumptions with respect to particular variables by different modelling teams. Notably RCPS create scope for so called narratives, which reflect variations in socioeconomic models and their assumptions. This will allow a greater range of assumptions to be evaluated and

will increase the modelling capacity to examine different ways to address climate change at both the global level and also at a more disaggregated regional scale. For further details on the RCPs see:
www.imedea.uib-csic.es/master/cambioglobal/Modulo_I_cod101600/Romu/AR5_Preliminar_Octubre_2013/RCPs_Overview.pdf

2.3.2 JRC scenarios

The Joint Research Centre of the European Commission developed four scenarios to describe the potential interactions between global food security and sustainability for the year 2030 as the proverbial 'day after tomorrow' (Figure 2.1):

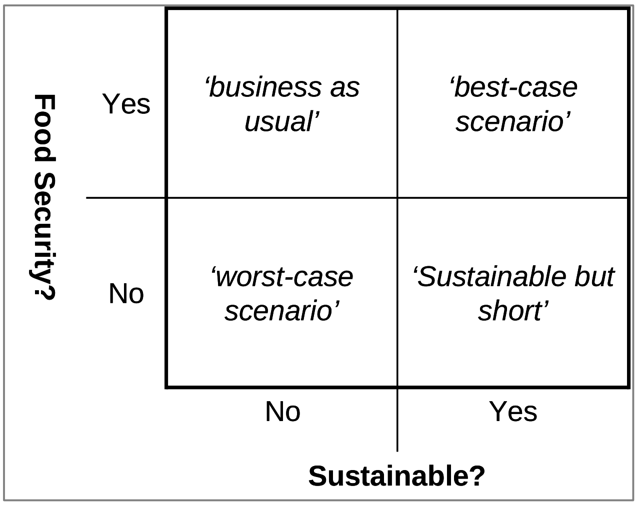


Figure 2.1: JRC scenarios on sustainable food security for 2030. The four scenarios are described as interactions between food security (vertical axis) and sustainability (horizontal axis). Source: JRC expert workshop on sustainable food security, Seville, 8-9 April 2013.

In the 'business as usual' scenario, global agricultural is increased in response to increased demand, but natural resources are depleted in the long-term. Although the supply of food is sufficient to meet total calorific demand in this scenario, both under-nutrition and over-nutrition persist in this scenario due to an inequitable distribution of food, with consumers in developed and emerging countries increasingly relying on 'concentrated foods', i.e. food with a large environmental footprint.

In the 'worst-case scenario', rapid depletion and overexploitation of natural resources prevent increases in agricultural productivity. High demand for unsustainably produced food in developed and emerging economies leads to both widespread under-nutrition and over-nutrition. Regional disparities in access to food accelerate, ultimately resulting in widespread land-grabbing and/or food protectionism.

In the 'sustainable but short' scenario, environmental concerns take precedence over food security. Technological advances are applied to reduce the environment footprint of food production, which is tightly regulated. Policies are aimed at adjusting the level of food production to minimise environmental impact, resulting in higher food prices. While in developed economies this has relatively little impact on access to food, it has significant negative consequences on access to food in developing and emerging economies. In effect, this scenario is only sustainable in terms of environmental sustainability, but not in terms of social sustainability.

In the 'best case scenario', agricultural production results in universal access to food that is sustainably produced. This is the result from simultaneous changes in the supply of food, through a process of sustainable intensification, and changes in the demand for food, through purposeful changes in dietary preferences in developed and emerging economies. This scenario is associated with global governance of food resources and sustainability along the entire food supply chain.

2.3.3 Animal Change storylines

Three storylines have been generated within the AnimalChange project (www.animalchange.eu).

SSP1 - Sustainability: Under this scenario the world is progressing towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. Elements that contribute are a) a rapid development of low-income countries, b) a reduction of inequality (globally and within economies), c) rapid technology development, and d) a high level of awareness regarding environmental degradation. The storyline is characterized by an open, globalized economy, with relatively rapid technological change directed toward environmentally friendly processes, including clean energy technologies and yield-enhancing technologies for land. Consumption is oriented towards low material growth and energy intensity, with a relatively low level of consumption of animal products. Investments in high levels of education coincide with low population growth. Concurrently, governance and institutions facilitate achieving development goals and problem solving. The Millennium Development Goals are achieved within the next decade or two, resulting in educated populations with access to safe water, improved sanitation and medical care. Other factors that reduce vulnerability to climate and other global changes include, for example, the successful implementation of stringent policies to control air pollutants and rapid shifts toward universal access to clean and modern energy in the developing world.

SSP 2 - Middle of the Road (or Dynamics as Usual, or Current Trends Continue, or Continuation, or Muddling Through): In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation or medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

SSP 3 - Fragmentation (or Fragmented World): The world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil fuel dependency, or addressing local environmental concerns such as air pollution. Countries focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Little international cooperation and low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and economic trends. Growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by high population growth, use of local energy resources and slow technological change in the energy sector. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavourable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity. Policies are oriented towards security, including barriers to trade.

3. Reference range: emissions, offsetting, and emissions gap

For our own appraisal of pathways towards carbon-neutral agriculture by 2050, we first need to ascertain a) the likely agricultural emissions by 2050; b) the magnitude of offsetting through carbon-sequestration and c) the resulting emissions gap that needs to be 'closed' to achieve or approach carbon neutrality.

In our second report (Schulte & Donnellan, 2012), we projected the likely agricultural emissions and offsetting potential for the year 2020 and we elaborated on the uncertainties surrounding these 8-year future projections. Agriculture in 2020 will likely be shaped by agricultural policies that are now largely determined and by technologies that are currently in us or near market – this allowed us to make projections with a reasonable amount of confidence. In this current study, we attempt to assess the emissions and offsetting over the period to 2050. Agriculture in 2050 may well be shaped by policies, market developments and technologies that are unknown at this point in time; hence uncertainties surrounding any projections will be greatly amplified. Therefore, any numerical projections in this report are associated with a very high degree of uncertainty and must be interpreted as such. In our appraisal of pathways to close this gap we remain cognisant of this uncertainty.

3.1 Emissions

We used the FAPRI-Ireland model (Hanrahan, 2001) to estimate agricultural emissions by 2050. For consistency with our previous reports, all estimates were based on the assumption that Food Harvest 2020 targets will be fully met by 2020. Projections for the period to 2050 were based on the recent publication by Donnellan *et al.* (2013), with associated assumptions on changes in output and input prices for the period 2021 to 2050. Under these assumptions the real price of agricultural commodities remains relatively fixed. In this reference scenario the amount of support available to agriculture through the CAP policy is assumed to remain unchanged in nominal terms, so the value of agricultural support payments declines in real terms over time. This is an important consideration given that support payments still make up about 70-80% of agricultural income in Ireland at the present time, with the balance provided by the market place.

These assumptions result in a scenario that suggests that:

1. Dairy cow numbers are likely to increase following the phasing out of EU milk quota and stabilise after 2030 (Figure 3.1);
2. Suckler cow numbers are likely to be reduced gradually in line with the long-term erosion of the real value of agricultural support payments (Figure 3.1);
3. In terms of total bovine stock numbers, the likely net result is a marginal increase up to *c.* 2030, followed by a stabilisation of animal numbers (Figure 3.2).

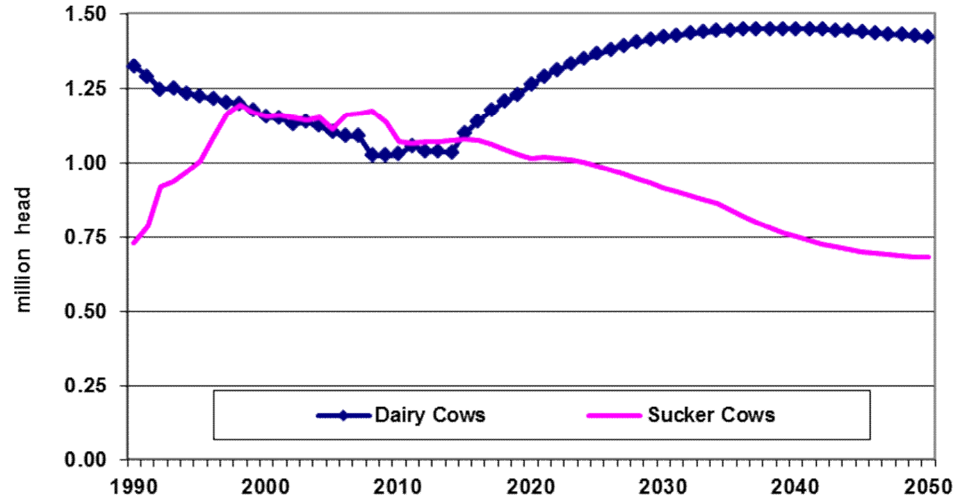


Figure 3.1: Projected dairy and suckler cow populations under the reference scenario. Source: Donnellan et al. *(2013).*

The consequences for GHG emissions over the projection period are that emissions would rise in the short to medium term, reaching about 22 Mt CO_2eq by 2030. Emissions would continue to rise beyond 2030 but at a much lower rate. The principal drivers for the increase in emissions are the growing populations of dairy cows (incl. beef progeny), pigs and poultry and associated increases in fertiliser emissions and emissions associated with animal waste. This overall growth in emissions would only be partially offset by a decline in the number of suckler cows and emissions associated with this category of activity (Figure 3.2)

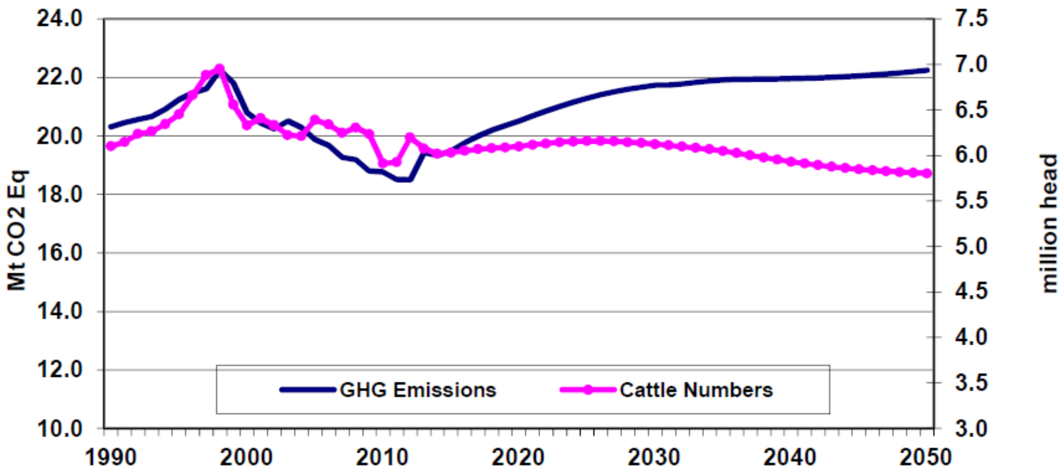


Figure 3.2: Projected agricultural GHG emissions and total cattle numbers under the reference scenario. Source: Donnellan et al. *(2013).*

3.2 Offsetting

The potential for offsetting through carbon sequestration depends on the following carbon sinks:

- grassland
- cropland
- peatland/wetland
- forestry: both carbon sequestration in forest biomass, litter, deadwood, soils and sequestration of carbon into harvested wood products (HWP) (see Section 4.2 for discussion on durability) and fossil fuel replacement abatement using forest fuelwood.

As discussed in Section 2.1.2, the EPA has previously estimated that current grassland and forestry in Ireland are carbon sinks, that cropland is carbon neutral, while peatland/wetland is currently a carbon source, resulting from the widespread historical (pre-1990) drainage of organic soils (O'Reilly *et al*., 2012; EPA, pers. comm.).

For our study, establishing the magnitude of the offsetting potential through sequestration by 2050 first requires estimation of:

- the average annual net sequestration potential of grassland;
- the annual net sequestration potential of forest plantations, as well as carbon sequestered in HWP and including fossil fuel replacement of forest wood fuel.

For the purpose of this exercise, we assume that cropland is and remains carbon neutral. Following personal communication with the EPA, net emissions from peatlands / wetlands are (roughly) estimated at 2.2 Mt CO_2eq by 2050 throughout this study.

3.2.1 Grassland sequestration rates

Increasing organic carbon levels in soil has been identified as offering the largest potential carbon sink for mitigating agricultural emissions with the IPCC estimating the removal of 5.5 to 6.0 Gt CO_2eq yr^{-1} by 2030 as technically-feasible (Smith *et al*. 2008). However, measurement and verification of this process is extremely challenging. The principal challenge in measuring soil C sequestration is that it is a decadal process, with small inputs (< 1 t C ha^{-1} yr^{-1}) being inputted into a large background (> 100 t C ha^{-1} in the top 30 cm soil). In addition, spatial heterogeneity superimposes additional uncertainty. As a result, the primary method for measuring C sequestration is to measure gaseous CO_2 fluxes in and out of ecosystems at a field or catchment scale using a technique called eddy covariance. The European grassland sequestration rate has been estimated using a continental wide network of CO_2 flux monitoring systems as part of the CARBOEUROPE initiative and is currently being upgraded as part of the Integrated Carbon Observation System (ICOS) which will run for the next 20 years.

Assimilation through photosynthesis (also termed gross primary production or GPP) is the primary pathway through which carbon enters terrestrial pools. Subsequently, between 40 and 50% of that carbon is returned to the atmosphere through plant or autotrophic respiration (Ra) with the remainder fixed as biomass and exudates. This biomass dies and is subsequently metabolised by soil fungi and bacteria (heterotrophs) with a large proportion of this biomass respired as heterotrophic respiration (Rh). This net balance between GPP and ecosystem respiration (Ra +Rh) is termed Net Ecosystem Productivity (NEP). This is the value that is most commonly reported when CO_2 fluxes are reported: these are usually between 2.5 – 6 t C ha^{-1} yr^{-1} (Soussana *et al*., 2007; Jaskic *et al*., 2008; Kiely *et al*., 2009; Abdalla *et al*., 2013). However, other losses must also be subtracted from this NEP value. They include (a) leached C, (b) exported C (harvested or grazed biomass), and (c) C lost as enteric methane from ruminants. In addition, C returned to the system as excreta of slurry should be added to the total. The final C balance is termed Net Biome Productivity (NBP). This total balance is shown in equation 1 below:

$$NBP = GPP - (R_a + R_h + DOC + E_C + VOC + CH_{4C}) + O_C \qquad \text{Equation 1}$$

Where GPP is gross primary productivity, R_a is autotrophic respiration, R_h is heterotrophic respiration, DOC is dissolved organic C, E_C is C exported in harvests or grazing, VOC is volatilised C, CH_{4C} is enteric methane C and O_c is organic returned to the system as plant or animal residues (see Smith *et al*., 2010 for further details).

As a consequence, NBP values are significantly lower and may even result in a net C loss in any given year. The European NBP has been quantified between 0.5 - 1.04 t C ha^{-1} yr^{-1} (Soussana & Luscher, 2007; Soussana *et al*., 2007). Measured values for Irish grasslands range between a sink of 1 t C ha^{-1} yr^{-1} and a source of -0.4 t C ha^{-1} yr^{-1} with a mean of 0.55 t C ha^{-1} yr^{-1} (Soussana *et al*., 2007; Gottschalk *et al*., 2007). Annual estimates are confounded by considerable inter-annual variation in values of NEP and NBP and this variation is driven by (a) management and (b) climatic (temperature, rainfall and solar radiation) factors. Indeed, grasslands were shown to be converted from a C sink to a source during the 2003 European heatwave (Ciais *et al*., 2005). As a result, there are concerns as to the permanence of these sinks under future climate change.

Projected C sequestration in Irish grassland soils was modelled using the DeNitrification DeComposition model (DNDC version 9.4; Li *et al*., 2003). The simulated sequestration rates assume that grasslands achieve a soil C equilibrium over a 70 -100 year period (Poeplau *et al*., 2012) with model runs based on 30-year averaged weather data. Future (2050) projections assumed a 1.0^{o}C temperature increase with 15% reduction in summer precipitation, a 15% increase in winter precipitation and that CO_2 concentrations increase at a rate of 2 ppm yr^{-1}. European monitoring of the European C sink Simulation runs had previously been validated against measured CO_2 flux data (see Abdalla *et al*. 2013 for details).

As a result, we estimate that the sequestration potential for grasslands will equate to 6.5 Mt CO_2eq per annum by 2030, rising to 6.8 Mt CO_2eq per annum by 2050. It should be noted, however, that increased weather volatility could substantially reduce this sink.

3.2.2 Forestry sequestration rates

Historical and projected carbon stock changes in forest pools were estimated using the Irish carbon accounting software (CARBWARE) based on a gains and losses approach, as described in detail in section 7.2 and the appendices of the NIR 2013 (Duffy *et al*., 2012) Forestry projections use national forest inventory (NFI) and roundwood harvest forecast (Phillips, 2011) state variables as inputs into the CARBWARE single tree growth and carbon flow model (Black *et al*., 2012, Duffy *et al*., 2012). The initial projections are based on a business and usual (BAU) scenario, which is assumed to reflect future afforestation rates, harvests, deforestation rates and harvest wood product flows based on trends and factors influenced by current policy. The influence of future commodity market prices on harvest and indirect human induced factors on future forest growth is not considered.

System boundaries and assumptions

1. Projections include all forest areas (i.e. pre-1990 forests, referred to as FM) and post 1990 afforestation (referred to as AR):

    i. Projections for FM land (land afforested before 1990) were initially run up 2030 using available NFI and harvest forecasts. No harvest forecast data is available after 2030. Therefore, we assume that FM lands GHG emission/removals are in steady state, based on a 20 year mean up to 2030. The harvest from FM land is also assumed to be the 20 year mean for 2010-2030 (3.2 M m^3 per year from 2031-2050). This is based on recent work conducted for DAFM. This assumption is realistic because FM lands should in theory be constant under a sustainable management scenario (i.e. increment should be slightly higher than removals). This is offset against deforestation and a reduction in the FM areas going forward.

    ii. A deforestation rate of 400 ha per year is assumed, based on most recent NFI results.

    iii. Afforestation from 2012 onwards is assumed to include the same species, productivity classes and soils as those currently being established. For the BAU scenario afforestation rates are assumed to be 8000 ha per year, which is consistent with recent afforestation grant trends and national targets.

2. Forest C pools (i.e. a ‘ life cycle approach’ proxy) including harvested wood products (HWP) from domestic harvest:

    i. Forest biomass, litter, deadwood and soil pools are included. Mineral forest soils are assumed to exhibit no stock change, based on current research and available data (Duffy *et a*l, 2012). An emission factor of 0.59 t C/ha/yr for 50 years of the first rotation is applied to peat soils using the same methodologies outlined in the National Inventory Report (NIR) (Duffy *et al*., 2012).

ii. Harvest assumptions are based on a modified version of the All Ireland roundwood forecast, now run for 2011-2030. Note: this is a potential harvest, so does not reflect timber supply/ demand and economic influences.
iii. Harvests for afforested lands after 2030 are based on silviculture guidelines using the British forestry commission yield class tables assuming 60 % of stands are thinned at marginal thinning intensity. Clearfells are assumed to occur at 20% of maximum mean annual increment for conifer crops. Note: this will not reflect the dynamic influence of harvest due to management decisions implemented that are not consistent with yield table prescriptions.
iv. All clearfelled stands, except for deforestation, are planted 2 years after felling with the same species.
v. Harvests for fuel-wood and energy production are assumed to replace fossil fuel mixtures using a counterfactual emission factor of 0.607 tCO_2/Mwh and a biomass energy value of 2.5 MWh per tonne is assumed based on a moisture content of 30%. Transport and processing emissions are based on a distance of 85 km between the forest and site where energy is utilised using an emission factor of 0.014 t CO_2/t biomass/km.
vi. Fuelwood use is assumed to increase in the projected harvest from 7% of total roundwood production in 2011, to 21% by 2030 and a constant rate of 21 % to 2050. This is consistent with bio-energy targets and timber demand projections.
vii. Fossil fuel replacement in timber mills is not considered, since this is not an additional activity.
viii. Long term HWP storage occurs in sawnwood and wood-based panels produced form domestic harvest only. No paper is currently produced from wood fibre in Ireland, but historical emission/reductions back to 1900 are considered.
ix. Projected allocation of roundwood harvest is assumed to be a function of top diameter assortments, where pulpwood is allocated to wood-based panels and assortments > 14 cm are allocated to sawnwood. These are derived using historical regressions of TDC and produced sawnwood or wood-based panels.
x. Historic consumption rates from 1900-1961, using a growth rate of 1.15% y^{-1}, were used to estimate emissions from products entering the system prior to 1961, as outlined in IPCC Guidelines for National Greenhouse Gas Inventories 2006 (IPCC, 2006). Default half-lives of two years for paper, 25 years for wood-based panels, and 35 years for sawn wood were used to estimate emissions resulting from products coming out of use (IPCC, 2006).

3. Emissions from fossil fuel emission due to forest activities not included.

4. Emissions of N_2O from nitrogen fertilisation are not estimated because CSO statistics do not provide separate estimated for forestry activities.

Permanence and temporal fluctuations

Factors such as variations in harvesting rates, wood utilisation trends and forest age class structure (Black *et al*., 2012) influence the temporal dynamics of carbon capture in forests. Therefore, it should be noted that the use of a single year sequestration rate, such as 2050 or 2030 does not reflect the long term trend since these are not in steady state (Figure 3.3).

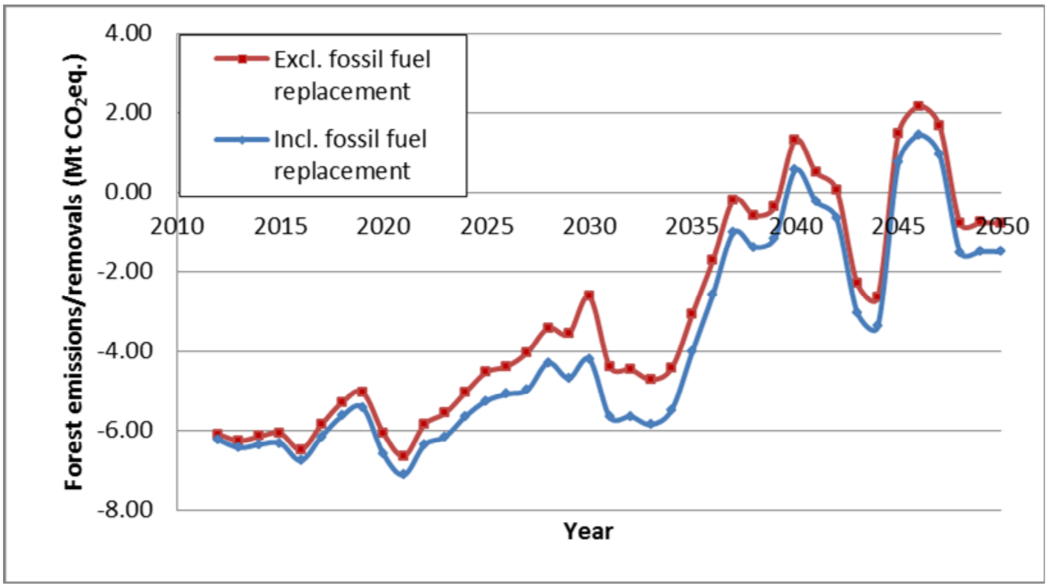


Figure 3.3: Projected GHG emissions for forest land (including and excluding fossil fuel replacement by fuelwood) under the reference scenario. Negative values represent a net removal of CO_2 (i.e. a forest sink) and positive values are an emission.

The projected decline in the forest sink and the large inter-annual fluctuations in trends can be attributed to the following factors:

- Increase harvest of timber from an average of 3 Mm^3 in the 2012 to over 6 Mm^3 by 2050.
- Fluctuations in timber harvest and assortments, which result in fluctuation on the removal by HWP.
- Increase timber utilisation for fuel wood.
- A change in age class structure of afforested land since 1990 resulting from clearfell and replanting of forests.
- Fluctuations in historic afforestation rates. Since 1995 afforestation rates have decreased from 25,000 ha to less than 8,000 per year by 2012. These declining historical afforestation rates result in an age class legacy (see Black *et al*., 2012). Black (2007) suggests that afforestation rates need to be maintained above 10, 000 ha per year to ensure the forest sink does not become a source by 2040-2050.
- It is likely that forest sinks will increase back to ca. 3 Mt CO_2 per year by 2060 due to a shift in age class structure and higher productivity of older replanted stands (Black, 2008; Black *et al*., 2012).

If we exclude fossil fuel displacement by forestry by-products, we estimate that the sequestration potential for forestry will equate to 2.6 Mt CO_2eq per annum by 2030, falling to 0.8 Mt CO_2eq per annum by 2050.

Including fossil fuel displacement, we estimate that the sequestration potential for forestry will equate to 4.2 Mt CO_2eq per annum by 2030, falling to 1.6 Mt CO_2eq per annum by 2050.

3.3 The emissions gap

Table 3.1 presents the emissions gap in the 'business as usual' scenario, defined as the difference between agricultural emissions (Section 3.1) and offsetting (Section 3.2):

Table 3.1: Total potential agricultural GHG emissions and offsetting, and the resulting emissions gap by 2030 and 2050 under the reference scenario (no mitigation). All figures in Mt CO_2eq per year; positive figures refer to net emissions, negative figures to net offsetting.

	2030	**2050**
Total agricultural GHG emissions	+21.7	+22.2
Forestry (incl. fossil fuel displacement)	*-2.6 (-4.2)*	*-0.8 (-1.6)*
Grassland	*-6.5*	*-6.8*
Cropland	*0*	*0*
Wetland	*+2.2*	*+2.2*
Total offsetting	-6.9 (-8.5)	-5.5 (-6.2)
Emissions gap (incl. fossil fuel displacement)	+14.8 (+13.2)	+16.7 (+16.0)

It shows that the emissions gap would likely equate to *c*. two-thirds of total agricultural emissions by 2030. It is of concern that the emissions gap is projected to widen between 2030 and 2050, and amount to 75% of total agricultural emissions by 2050. This would largely be the result of the projected decline in the offsetting potential of existing forestry during this period, as outlined in section 3.2.2. When including the fossil fuel displacement potential from forestry by-products, the emissions gap would be somewhat lower, but would rise during the 2030-2050 period.

These figures are graphically visualised in Figure 3.4:

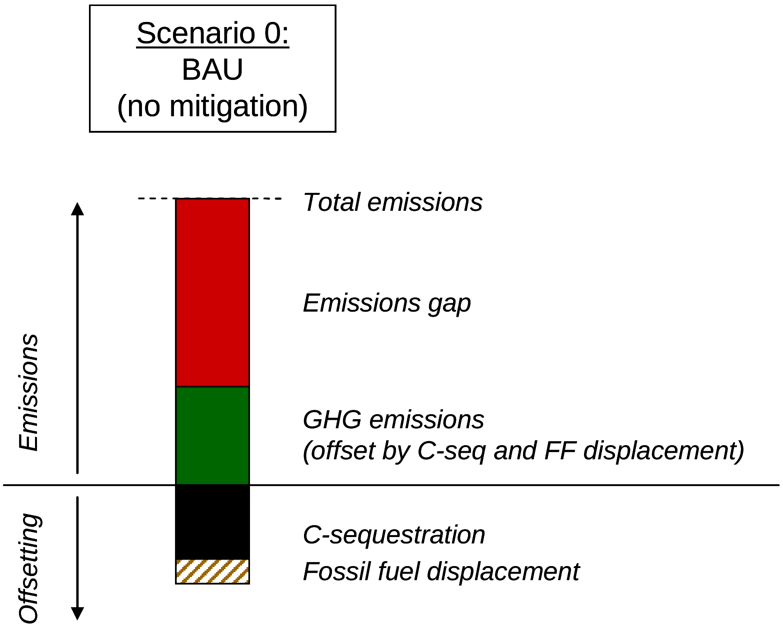


Figure 3.4: Illustration of the projected emissions gap. The black bar below the line indicates sequestration, the dashed brown bar indicates fossil fuel displacement, the green bars indicate agricultural GHG emissions that are offset by sequestration and fossil fuel displacement, while the red bars indicate the emissions gap, i.e. that part of the emissions that is neither offset, nor mitigated in the business as usual scenario.

4. Evaluation of Pathways towards Carbon-Neutral Agriculture

In this section we present an overview of a number of pathways that might be followed to bring about a carbon neutral agriculture sector in Ireland. Each of these five pathways is described in details and each pathway is subjected to a multi-criteria analysis to evaluate its efficacy.

4.1 Overview

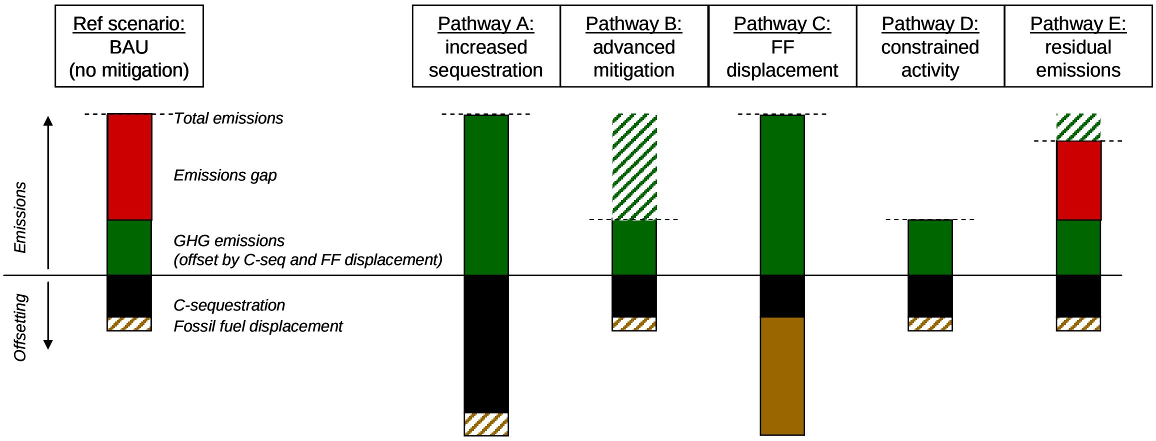


Figure 4.1: Visual representation of the five pathways towards carbon-neutrality assessed in this report. Black/grey bars indicate carbon-sequestration, dark green bars indicate the part of agricultural emissions that is offset by sequestration, dashed bars indicate mitigated emissions, the light green bar indicates emissions offset through specific pathway measures, while the red bar indicates an emissions gap. Each pathway is explained in detail in the text.

We consider five pathways towards carbon-neutral agriculture in this report. These are:

A. 'Increased sequestration: in this pathway, the emissions gap is closed by accelerated carbon sequestration in forestry or grassland (Section 4.2);

B. 'Advanced mitigation': in this pathway, the emissions gap is closed by advanced mitigation measures (Section 4.3), i.e. either:

   i. Measures that were identified in our MACC;

   ii. Measures that are subject to current research and were not (yet) included in our MACC;

   iii. New measures that may arise and researched between now and 2050.

C. 'Fossil fuel displacement': in this pathway, the emissions gap is offset by displacement of fossil fuel imports through the cultivation of biofuel/bioenergy crops and through anaerobic digestion of surplus grass (Section 4.4);

D. ‘Constrained agricultural activity’: in this pathway, agricultural activity is reduced to such an extent that agricultural emissions equal net offsetting (Section 4.5);

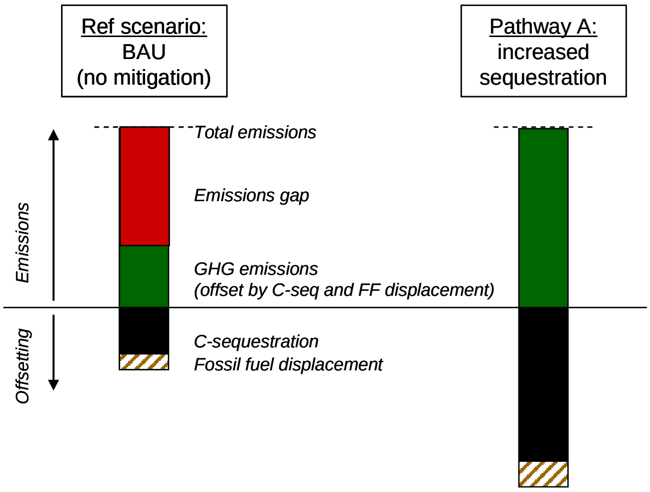
E. ‘Residual emissions’: in this pathway, the emissions gap is not fully closed (Section 4.6).

We consider each of these five pathways *in isolation*, in order to fully explore their potential and limitations. Therefore, in this assessment each of the pathways represents an *extreme* scenario, with one singular pathway towards closing the emissions gap. In the Discussion (Section 5), we will consider combinations of the various pathways.

For each of these five pathways, we report on the following considerations:

1. Pathway narrative: a brief description of the pathway;
2. Pathway description: a technical description of how the pathway closes the national emissions gap through mitigation or offsetting;
3. Pathway constraints: constraints to full or partial implementation of the pathway;
4. Multi-criteria assessment: contextual considerations, specifically:
    - impact on farm profitability and the rural economy
    - its effectiveness in contributing to a reduction in global agricultural GHG emissions (i.e. consideration to carbon-leakage and food security concerns)
    - impact on farm productivity and economic viability
    - impact on land requirement and competition between land uses
    - potential impact on other environmental indicators (note that a full environmental impact assessment is outside the scope of the current document)
    - resilience of the pathway to climate change.
5. Summary assessment: finally, for each pathway we derive a summary assessment of its potential to reduce the national emissions gap for agricultural GHGs.

4.2 Pathway A: Increased sequestration



4.2.1 Pathway A: Narrative

The 'accelerated sequestration' Pathway focuses on maximising the offsetting of agricultural GHG emissions through carbon sequestration in biomass, litter, deadwood, soils and in harvested wood products. There are three mechanisms through which carbon-sequestration can be enhanced at national level:

1. stimulating carbon-sequestration in permanent tillage soils
2. enhancing carbon-sequestration rates in grasslands, over and above current levels
3. planting of new forests, involving land use change

The technical potential of the first mechanism, carbon-sequestration in tillage soils, was reviewed by Spink *et al*. (2010). Whilst there is merit in maintaining carbon (organic matter) concentrations in tillage soils in order to maintain soil quality (e.g. soil structure, nutrient cycling, etc.), the potential of this mechanism in offsetting emissions at national scale is limited, due to the biophysical nature and limited geographical extent of tillage soils in Ireland.

The second mechanism, enhanced carbon-sequestration in grassland soils, is the subject of current international and national research. As discussed in Section 3.2.1, the sequestration potential of grasslands varies significantly between years and between soils, necessitating long-term experiments and monitoring programmes. These research efforts are now sufficiently mature to provide first indications of current sequestration rates. However, the scientific literature is as of yet inconclusive on the potential for *further* enhancement of carbon sequestration rates in grassland. Therefore, in this pathway we focus on the potential of the third mechanism: accelerated afforestation, over and above the current afforestation rates assumed in the BAU scenario.

Currently, in Ireland forests account for *c.* 0.74 million hectares or *c*. 10% of total land cover, which is well below the EU average of *c*. 40%. Recent decades have seen a consistent increase in forest cover, although annual planting rates have varied significantly between years since 1995, from a high of 23,710 hectares p.a. to a low of 6,420 hectares p.a. (Black *et al*., 2012). Current afforestation rates stand at *c*. 8,000 hectares per annum.

In principle, there is scope to increase national afforestation rates. Historical planting rates suggest that increasing the annual afforestation rate from 8,000 to 20,000 hectares is both technically and logistically feasible. If (hypothetically) this increase in planting rate were to be achieved instantly and maintained up to 2050, this would result in a doubling of the total current forest cover to *c.* 1.5 million hectares by 2050. In a forthcoming report on the potential for afforestation in Ireland (Farrely *et al*., in prep), Teagasc will address this question in detail. The report will show that whilst – in principle – there is sufficient suitable land area available for forestry, to meet the planting rates assumed in the BUA scenario without undue competition for land with intensive agricultural production, the availability of land may ultimately restrict full implementation of pathway A. Of greater significance in the short-term though is that afforestation on this suitable, underutilised land area is currently subject to significant policy related constraints, which are discussed in Section 4.2.3 below.

Using the CARBWARE model (Black *et al*., 2012; Duffy *et al*., 2012), we estimate that an immediate increase in the annual afforestation rates from 8,000 to 20,000 would result in a potential net carbon-sequestration potential from forestry of 7.5 Mt CO_2eq p.a. (8.8 Mt CO_2eq p.a. when including fossil fuel displacement associated with forestry). This represents an increase in offsetting potential of 6.7 Mt CO_2eq p.a. (7.3 Mt CO_2eq p.a. including fossil fuel displacement) over and above the Reference scenario.

4.2.2 Pathway A: Technical description

Carbon-sequestration in new afforestation consists of three components:

1. Additional carbon sequestration in forests: this is most prominent in first-cycle (i.e. new) plantations because the C storage capacity of an afforested area is likely to reach a steady state over successive rotations (see Figure 4.2). This implies that the additional sequestration potential of an area is close to zero once the first rotation is complete; mitigation potential is therefore once-off, unless forest management practices over and above the normal practice are implemented. These may include altering thinning strategies, rotation lengths or the introduction of new silvicultural practices, such as shelterwood (continuous cover) silvicultural systems (Black, 2008).
   a) The total sequestration potential of afforestation during the first rotation depends to a large extent on the choice of species mixture and the soil type on which the forestry is planted. For our pathway assessment, we assumed historic species mixtures and soil types.

b) If, instead, the species mixtures were to be optimised for sequestration potential, and if new afforestation were to be targeted on suitable, non-peat soils, then this could increase the total offsetting potential of afforestation by a further 20-30% (Ní Dhubháin *et al*., 2013).

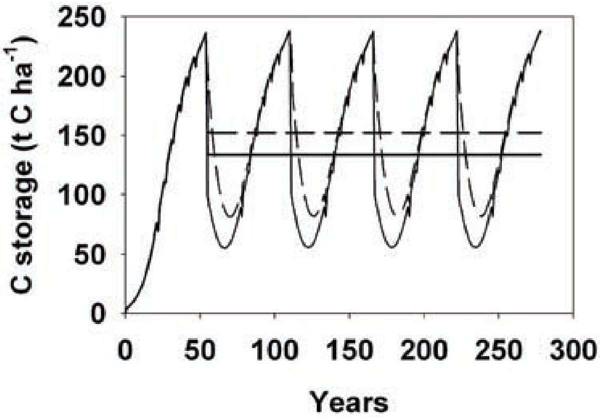


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Figure 4.2: Predicted changes in C storage over five rotations of thinned Sitka spruce (YC16, 2 m spacing on mineral gley soils) plantations, assuming immediate wood C loss at harvest (solid line) or harvested wood product storage (broken line). Taken from Black et al. (2008).

2. Harvested wood product sequestration would increase as additional planted forest is harvested, starting in ca. 2030. The inflow of wood products into this pool could vary depending on harvest and timber assortments allocated to different wood products and the proportion of harvest used for fuel wood.
    a. Harvest levels depend on silvicultural management decisions, such as no thinning options in cases where windthrow risk is high or where it is not economically viable to thin stands. Under a no thin scenario, the HWP storage is potentially reduced due to a higher allocation of smaller assortment timber into wood products with a lower long term sequestration potential (e.g. pulp or wood-based panel products with half-lives of two to 25 years, compared to 35 years for sawnwood products of 35 years). For our pathway we assumed the business as usual scenario where 40 % of stands are not thinned.
    b. If future incentives are created to enhance timber resource utilisation in the private sector, it is plausible that silvicultural management may change. This would influence both the storage capacity in forests and HWP.
    c. Product substitution with wood products, such as use of timber in construction instead of concrete, can also increase long term HWP sequestration. This study does not consider life cycle analysis with regards to embodied energy/CO_2 emission savings in substituted products or reduced heating requirements.

3. Fuelwood utilisation is projected to increase to meet renewable energy targets. Therefore, fuelwood use and fossil fuel replacement would increase if potential harvest increases as a result of a higher afforestation rate as applied in this pathway. Future renewable energy targets and timber prices influencing fuelwood utilisation are not considered in this study. We do not consider fossil fuel substitution in timber mills because this is not deemed to be an additional activity (i.e. more wood would be used to produce energy for more timber production in mills).

Textbox 4.1 lists the assumptions underpinning the assessment of Pathway A.

Text box 4.1: Technical assumptions underpinning the offsetting projections of Pathway A

Land use
- 400 ha per year deforestation
- 100 ha per year forest fires
- Pre-1990 forest assumed to be in steady-state, based on 20-year mean, after 2030

Harvestable wood products
- No paper produced from wood fibre
- Include domestic production from domestic harvest only
- Fuel use increases by 2.2 M m^3 by 2030 and stays at a constant proportion of 21 % of total harvest up to 2055, fuelwood is oxidised immediately in HWP pool but accounted for under fossil fuel replacement
- Note: About 50% of harvested roundwood enters the HWP inflow stream, the rest is used for mill energy, or industrial residue, which is immediately oxidised

Harvest
- Harvest up to 2030 used the all Ireland roundwood forecast (Phillips 2011)
- Harvest for post 1990 forest after 2030 is based on silvicultural assumption that 40 % of conifer stands are thinned at MTI and rotation age is MMAI less 20%
- Harvest for pre-1990 forest assumes 20 year mean, based on data derived from Ireland roundwood forecast 2011-2030 (Phillips, 2011)
- Harvests are indicative and based on potential harvest only. There is no consideration of timber supply/demand and economic influences. This would be important in the future because it is suggested that timber price may drop due to higher supply internationally. This would also depend on bio-energy demand and future emission reduction targets.

Fossil fuel replacement
- Fossil fuel replacement in timber mills is not considered, since this is not additional
- Timber for fuel or energy production is assumed to replace a fossil fuel mixture using a counterfactual emission factor of 0.607 t CO_2 MWh^{-1}
- A biomass energy value of 2.5 MWh per tonne is assumed based on a moisture content of 30%
- Transport and processing emissions are based on a distance of 85 km between the forest and site where energy is utilised using an emission factor of 0.014 t CO_2 t^{-1} biomass km^{-1}

4.2.3 Pathway A: Constraints

Notwithstanding the significant potential of pathway A in offsetting agricultural GHG emissions, there are significant constraints associated with this pathway. The most immediate of these pertains to constraints on land use: Pathway A sees the afforested land area in Ireland double from *c.* 0.75 at present to 1.5 million hectares by 2050. In a forthcoming Teagasc report on the potential for further afforestation in Ireland, Farrelly *et al*. (in prep) show that the *bio-physical* area of soils that are suitable for afforestation and that are not being used (nor likely to be used) for intensive agricultural production, may ultimately constrain full implementation of Pathway A. It is important to note that this bio-physical area estimate already excludes land unsuitable for planting, such as blanket peats and raised bogs. However, the areas which are bio-physically suitable are currently subject to significant conservation and administrative constraints which preclude their use for forestry. Conservation constraints include:

- NATURA 2000 sites, in which conservation of existing habitats is prioritised;
- 6 km exclusion zones in Freshwater Pearl Mussel Catchments;
- Acid-sensitive catchments: in these catchments, restrictions mainly pertain to the planting of coniferous forestry.

The main administrative constraint is the requirement that new plantations include a maximum of 20% of unenclosed land. Both these conservation and administrative constraints will be discussed in detail in Teagasc's forthcoming report (Farrely *et al*., in prep.)

If we widen our view to a *post*-2050 scenario, limitations to land availability will ultimately constrain further expansion of the forestry area, and hence the offsetting potential of Pathway A, since this potential is highest for first-cycle afforestation.

Other constraints include:

- *Incentivisation:* annual afforestation rates are related to financial incentivisation schemes. Since the financial returns from forestry (as opposed to other enterprises e.g. livestock agriculture) take place on a long-term, rather than an annual, basis, the required 150% increase in annual planting rates is likely to require a significant incentivisation scheme. In addition, in some cases a change from livestock farming to forestry may be perceived to be in conflict with cultural values associated with livestock farming.

- *Immediacy:* our pathways assessment is based on the (unlikely) assumption that planting rates are *immediately* increased from 8,000 to 20,000 hectares per annum. The total estimated sequestration potential by 2050 is highly sensitive to the duration, and hence the starting date, of these higher rates of afforestation, along the principles of 'compound interest'. Therefore, full realisation of the offsetting potential of this pathway would require an immediate and urgent acceleration of the afforestation programme. Our assessment suggests that later starting points will result in a disproportionally lower offsetting potential associated with this pathway.

- *Permanence:* part of the offsetting potential from forestry arises from 'locking' carbon into durable wood products. Current inventories assume a typical lifespan for durable wood products of 100 years for half lives of 35 years (IPCC, 2006). However, on a centurial timescale, the carbon locked into these products will ultimately be released through oxidation. Whilst this does not affect our assessment for 2050, it does have consequences for the permanency of afforestation as an offsetting mechanism beyond 2050.

4.2.4 Pathway A: Multi-criteria assessment

The multi-criteria assessment for Pathway A is listed in Table 4.1:

Table 4.1: Contextual considerations for Pathway A

Consideration	**Assessment**
Impact on farm profitability / rural economy	This depends in first instance on the availability of financial incentivisation schemes. Financial returns from forestry operate on a long-term, rather than an annual basis.
Impact on global agricultural GHG emissions	Pathway A is unlikely to result in carbon leakage. It is projected to contribute to global offsetting of agricultural emissions.
Competition for land / land availability	Significant potential for competition for land between pathways A and C. Availability of land is dependent on the physical land base of suitable land for forestry, as well as conservation and administrative constraints. In the long-term, Pathway A may result in competition for land with primary agricultural production. Higher sequestration rates (per hectare) can be achieved by avoiding afforestation on peat soils. A degree of planning may be required to negate potential competition between agriculture and forestry. Continued afforestation after 2050 is likely to result in direct competition for land between agriculture and forestry. See Schulte *et al*. (2013) for a comprehensive assessment.
Potential impact on other aspects of environmental sustainability	Depending on previous land use, afforestation may impact on the wider environment through acidification, sedimentation, eutrophication, shading and light occlusion, hydrological flow changes and alterations to habitat type. Most of these impacts arise from forestry operations, rather than from the standing biomass itself. Since 2000, the Forest Service of the DAFM has published a number of environmental guidelines to control these operations e.g. Forestry and Water Quality Guidelines (2000); Code of Best Forest Practice – Ireland (2000); Forest Harvesting and Environment Guidelines (2000); Forestry and Aerial Fertilisation Guidelines (2001); Forestry Schemes Manual (2003); Native Woodland Scheme Manual (2008); and Forestry and Freshwater Pearl Mussel Requirements: Site Assessment and Mitigation Measures, (2008). The implementation of the procedures outlined in these guidelines is overseen by the Forest Service Inspectors.

Resilience of pathway to climate change	Pathway A is sensitive to climate change, specifically to potentially increased prevalence of pests, diseases, droughts, forest fires and strong winds. These risks should be accounted for in choice of species mixture and site suitability assessments. For details see Section 6.3 in Teagasc's first Greenhouse Gas report (Schulte & Lanigan, 2011).

4.2.5 Pathway A: Assessment summary

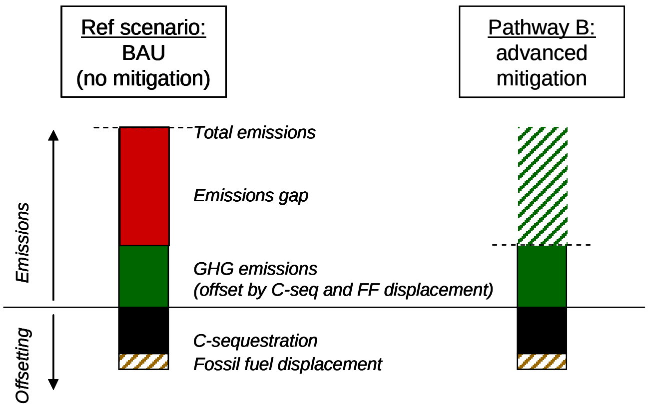
Pathway A shows considerable scope to reduce the national agricultural emissions gap by almost half, mainly through a process of accelerating new planting rates from 8,000 to 20,000 hectares per annum. Similar planting rates have been achieved in the past and hence these rates can be considered both technically and logistically feasible. Therefore, Pathway A could be considered under the heading of Track 3 of the NESC Secretariat report ('Design and Implement').

However, new afforestation is currently severely restricted by conservation and administrative constraints. While a change in policy and regulation is unlikely for some of these constraints (e.g. NATURA 2000 sites), other blanket constraints could potentially be made less onerous if higher-resolution site-suitability studies of potential forestry areas were employed and by the selective use of species mixtures in order to minimise the ecological and environmental impact of carbon-sequestration through afforestation. This would require an additional consideration of Pathway A under the heading of Track 1 of the NESC Secretariat report ('Strategic and Institutional').

Full realisation of the offsetting potential of Pathway A requires urgent incentivisation of farm afforestation, as it is disproportionally dependent on an 'early start' to higher planting rates. In addition, the efficacy of Pathway A can be maximised optimisation / targeting of species mixtures and suitable soil types.

It is important to note that the efficacy of Pathway A may be reduced at some point between now and 2050, as ultimately it is like to result in competition for land with agriculture. In addition, pathway A is likely to impact on other aspects of environmental sustainability, and is likely to show sensitivity to climate change.

4.3 Pathway B: Advanced mitigation



4.3.1 Pathway B: Narrative

In the 'advanced mitigation' Pathway, the emissions gap is reduced, with no associated reduction in productivity, through technological and farm managerial interventions and solutions. This pathway gives a central role to science, technology and knowledge transfer (KT).

In our second report (Schulte & Donnellan, 2012), we published a Marginal Abatement Cost Curve (MACC) for Irish Agriculture, which listed and assessed the efficacy and cost-effectiveness of 'proven' technological and managerial mitigation measures. Measures included in the MACC (in order of cost-effectiveness) were:

1. Accelerated gains in the Economic Breeding Index (EBI)
2. Accelerated weight gain in beef cattle
3. Extended grazing (beef)
4. Extended grazing (dairy)
5. Nitrogen efficiency (incl. use of clover)
6. Minimum tillage
7. Biomass / bioenergy production, including:
    a. Solid biomass for heat
    b. Solid biomass for electricity
    c. Oil Seed Rape for biodiesel / PPO + straw use
    d. Wheat bioethanol + straw use
    e. Sugar beet bioethanol
8. Cover crops
9. Slurry management (bandspreader / trailing shoe)
10. Anaerobic digestion (pig slurry)
11. Nitrification inhibitors

These measures above were ranked according to cost-effectiveness: measures 1-6 were classified as cost-beneficial; measures 7-8 were classified as either cost-neutral or cost-efficient, while measures 9-11 were classified as cost-prohibitive. See Schulte & Donnellan (2012) for full details.

This MACC provides a ‘snapshot’ of mitigation measures that are currently known to be effective in reducing GHG emissions from agriculture. Our report estimated the total combined mitigation potential of the cost-beneficial, cost-neutral, and cost-effective measures at *c.* 1.1 Mt CO_2eq by 2020, equating to 5.5% of total projected agricultural emissions for 2020 (using IPCC inventory computation conventions).

However, as briefly described in our second report, there are many more potential mitigation measures that are currently the subject of national and international research. These measures may become available for adoption in the future. This is often referred to as the ‘conveyor’ belt of research, where concepts are often trialled initially in a laboratory environment, followed by plot / animal trials and farm evaluation trials, a process which can take many years to complete. Figure 4.3 lists some of the GHG mitigation measures that are currently subject to national and international research (adapted from Lanigan & Rees, 2012).

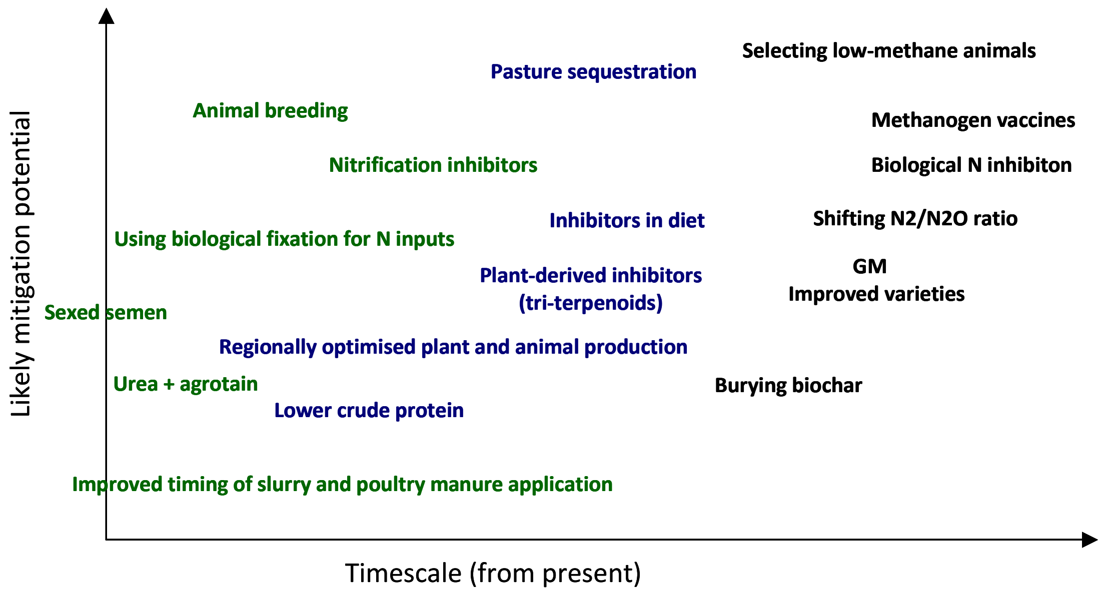


Figure 4.3: Freestyle illustration of the ‘research conveyor belt’, listing the GHG mitigation measures that are currently subject to national and international research. Colours indicate the time-period over which the various mitigation options may become deployable, measurable and reportable. Source: adapted from Lanigan & Rees (2012).

Before any of these measures can be included in any future iteration of the MACC, sufficient research data has to be available to assess: i) their efficacy in reducing GHG emissions while maintaining productivity under controlled experimental conditions; ii) their efficacy in a real-life farm environment; iii) their potential interactions with other mitigation measures and farm management aspects; iv) their costs-benefit ratios.

Our current MACC for Irish Agriculture was based on a comprehensive 10-year interdisciplinary research programme, which resulted in a combined mitigation potential of

1.1 Mt CO_2eq using IPCC inventory methods, or 2.5 Mt CO_2eq when using Life Cycle Analysis (LCA) calculation methods. Therefore, a first-order estimate would suggest that over the last 10 years, research has expanded the total national mitigation potential by approximately 0.11-0.25 Mt CO_2eq per year.

It is impossible to forecast to what extent this total mitigation potential can be expanded on over the period to 2050. Whilst some of the emerging measures are now 'close to roll-out' (see example of sexed semen in Section 4.3.2), the efficacy of many of the other measures currently under research is as of yet unknown. On the one hand, there are three reasons to expect that the roll-out of new measures may be accelerated over the time-period to 2050:

1. The mitigation potential of many of the measures in the MACC resulted as 'co-benefits' from completed research projects that were primarily focussed on improving agricultural production. Ongoing research (the results of which are likely to be included in future iterations of the MACC) focuses more explicitly on identifying strategies to reduce the carbon-intensity of agricultural produce.
2. Internationally, the amount of research funding committed to mitigation of GHG from agriculture has risen significantly in recent years;
3. Research, as well as research funding, is increasingly being coordinated in multi-disciplinary and multi-lateral networks of research collaboration (see Section 4.3.2 below). Such collaborative initiatives provide synergies and critical mass in national and international research and avoid undue duplication and could thus result in more effective delivery of emerging measures.

On the other hand, there are reasons to expect that the roll-out of new measures may decelerate between now and 2050. This will be the case if the measures identified to date in our MACC represent the 'low-hanging fruit' of mitigation, both in terms of their efficacy and their cost-effectiveness. For example, it is widely accepted that the mitigation of methane emissions from bovine animals, which currently accounts for approximately half of agricultural emissions, is particularly challenging, compared to e.g. the mitigation of nitrous oxide emissions. Therefore, as the roll-out of current mitigation measures reduces nitrous oxide emissions, the share of methane emissions increases in the agricultural emissions profile, potentially making further reductions more onerous.

As a result, we refrain from any attempts to quantify the total mitigation potential of Pathway B in this current assessment, other than to conclude that:

- It is unlikely that the emissions gap by 2050 can be met or 'closed' by Pathway B alone (see also Garnett, 2008);
- It is likely that Pathway B will play an important role in reducing national emissions from agriculture by 2050, and thus 'narrow the emissions gap'. This narrowing of the emissions gap will make the offsetting targets for Pathways A and C (somewhat) less challenging.

Pathway B could therefore be considered under both Track 3 (MACC) and Track 2 (emerging measures) proposed by the NESC Secretariat report.

4.3.2 Pathway B: Technical description

The technical and scientific basis for each of the mitigation measures included in the first iteration of the MACC is described in detail in our second report (Schulte & Donnellan, 2012). Textbox 4.2 explains the details of an emerging measure, i.e. 'sexed semen' that is close to market.

Text box 4.2: Example of a new measure 'close-to-market': sexed semen

The main output of dairy farming is milk. Dairy cows are required to produce milk and after a number of lactations these dairy cows must be replaced. These replacements are drawn from female calves within the dairy herd and the surplus calves are typically raised for beef. The genetics of these calves is therefore important. Ideally replacements for the dairy herd should possess the genetics to produce milk, while the surplus calves to be raised for beef should ideally have beef genetics, to maximise their growth potential before slaughter.
To date, dairy farmers (operating a typical annual replacement rate of 23% of dairy cows) would inseminate approximately 46% of their cows with semen from a dairy bull, resulting in (on average) 23% dairy heifer calves and 23% dairy bull calves. The latter bull calves represent an inefficiency in the dairy production system, as these dairy bull calves are inefficient producers of beef.

One example of a measure ready for roll-out is 'sexed semen': it is now technically possible to separate the semen of breeding bulls into male and female offspring. The sexing of semen allows farmers to maintain a 23% replacement rate while only inseminating just over 23% of cows with exclusively female dairy semen – leaving the remaining 77% of cows to be served by beef bulls, ensuring more efficient beef production with a lower carbon-footprint.

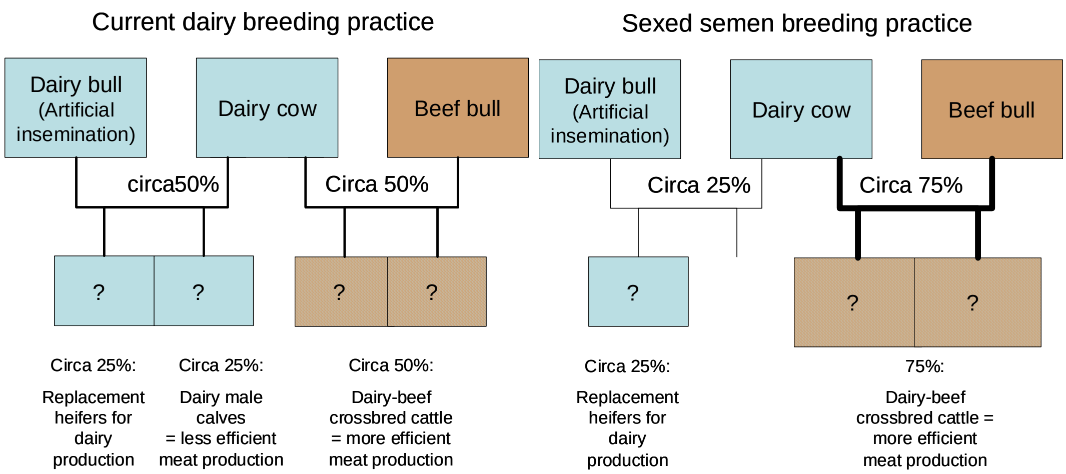


Figure 4.4: Visual illustration of the mechanism through which 'sexed semen' can reduce greenhouse gas emissions from dairy/beef systems.

The potential impact of 'sexed semen' on national agricultural GHG emissions is currently subject to ongoing research, but is likely to be significant, with a potential marginal reduction in GHG emissions (compared to the reference scenario) of *c.* 5%.

Other potential measures are currently being pursued by Irish research organisations include:

- Assessing dietary options in young animals: Modification of the rumenal environment of young cattle may result in more sustained methane reduction in response to diet.
- Shifting N_2O production to N_2 production: N_2O is a by-product of partial denitrification and nitrification. If denitrification can be shifted to total or co-denitirifcation to N_2, this results in a reduction in N_2O emissions and nitrate available for leaching.
- The use of autotrophic bacteria to directly fix CO_2 into the soil

The national research activities are coordinated under the umbrella of the Agricultural GHG Research Initiative for Ireland (AGRI-I) funded by the Department of Agriculture, Food and the Marine (DAFM) as part of the Research Stimulus Fund. The Initiative's primary objective are to a) refine agricultural GHG emission factors in order to increase the flexibility of the national inventory so that mitigation strategies can be included, b) assess the Carbon storage in Irish pastures, c) advance methane research in young ruminants d) refine biogeochemical models for use on a national scale and e) provide co-ordination for GHG methodologies and archive GHG datasets.

International examples that Irish researchers and research funders participate in include:

- The Global Research Alliance (GRA): The Global Research Alliance on Agricultural Greenhouse Gases is founded on the voluntary, collaborative efforts of countries. The Alliance is focused on research, development and extension of technologies and practices that will help deliver ways to grow more food (and more climate-resilient food systems) without growing greenhouse gas emissions. Members of the Alliance aim to deepen and broaden mitigation and adaptation research efforts across the agricultural sub-sectors of paddy rice, cropping and livestock, and the cross-cutting themes of soil carbon and nitrogen cycling and inventories and measurement issues. Groups have been set up to address these areas of work. These Groups have developed work plans that bring countries and other partners together in research collaborations, as well as to share knowledge and best practices, build capacity and capability amongst scientists and other practitioners, and move towards breakthrough solutions in addressing agricultural greenhouse gas emissions. The Alliance promotes an active exchange of data, people and research to help improve the ways that agricultural greenhouse gas research is conducted and to enhance participating countries' scientific capability. Alliance members work with farmers and farmer organisations, the private sector, international and regional research institutions, foundations and non-governmental organizations to improve the sharing of research results, technologies and good practices, and to get these out on the ground. See http://www.globalresearchalliance.org/ for further information.

- The EU Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI). This EU initiative coordinates the various *national* research strategies across the EU, funded by national R&D programmes (which represent *c*. 90% of public R&D funding in the EU). Following an extensive research mapping exercise and stakeholder consultation, this initiative has drawn up a Strategic Research Agenda, which informs national research programmes across the EU on research priorities. In addition, it has established a knowledge hub and is funding several multi-lateral calls for research on agriculture, food security and climate change. The initiative is led jointly by the Institute National de la Recherche Agronomique (INRA, France) and the Biotechnology and Biological Sciences Council (BBSRC, UK). DAFM and Teagasc are members of the Governing Board and Teagasc is Workpackage Leader (International Coordination) of the Coordination and Support Action of FACCE-JPI. For details, see: www.faccejpi.com

4.3.3 Pathway B: Constraints

An essential consideration for Pathway B is the central role of Knowledge Transfer (KT) in linking research findings with implementation on the tens of thousands of farms in Ireland. At global scale, Koning & Van Ittersum (2009) warn that achieving the technical potential for food production may well be hampered by social and economic factors, resulting in a knowledge gap between research and farm practices.

A particular challenge in the translation of research findings to farm advice is the diversity of the farming systems, as well as the diversity of the physical environments in which farmers operate. This is exemplified by the wide distribution in the carbon-intensity of 199 beef farms (i.e. emissions per kg live weight) observed in a detailed study by Crosson *et al*. (2013), as illustrated in Figure 4.5.

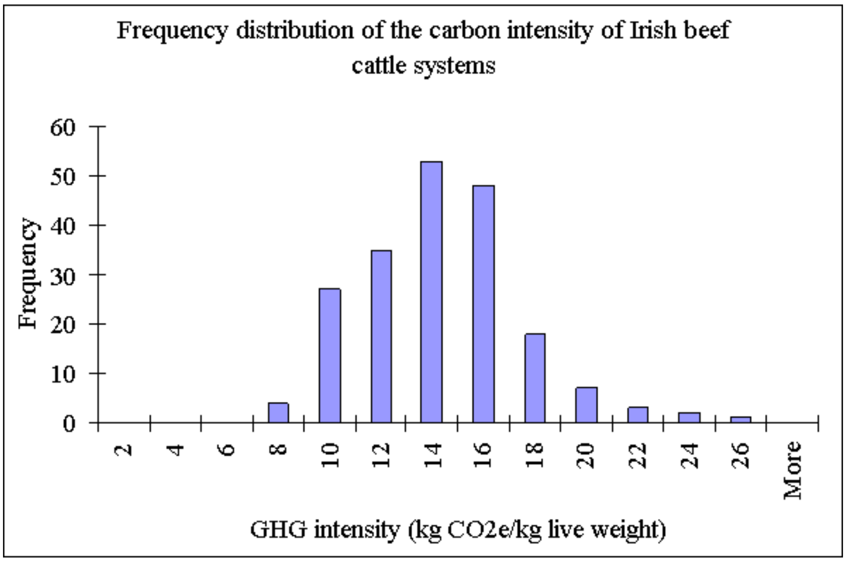


Figure 4.5: Frequency distribution of the carbon intensity (kg CO_2eq per kg live weight) of 199 Irish beef cattle systems. Source: Crosson et al. *(2013).*

Figure 4.6 visualises the twin roles of research and KT: whereas research on new GHG mitigation options aims to further reduce the carbon-intensity of farms that are already carbon-efficient, KT efforts focus on narrowing the spread in carbon-intensities between the most efficient producers and the ‘peloton’ of producers.

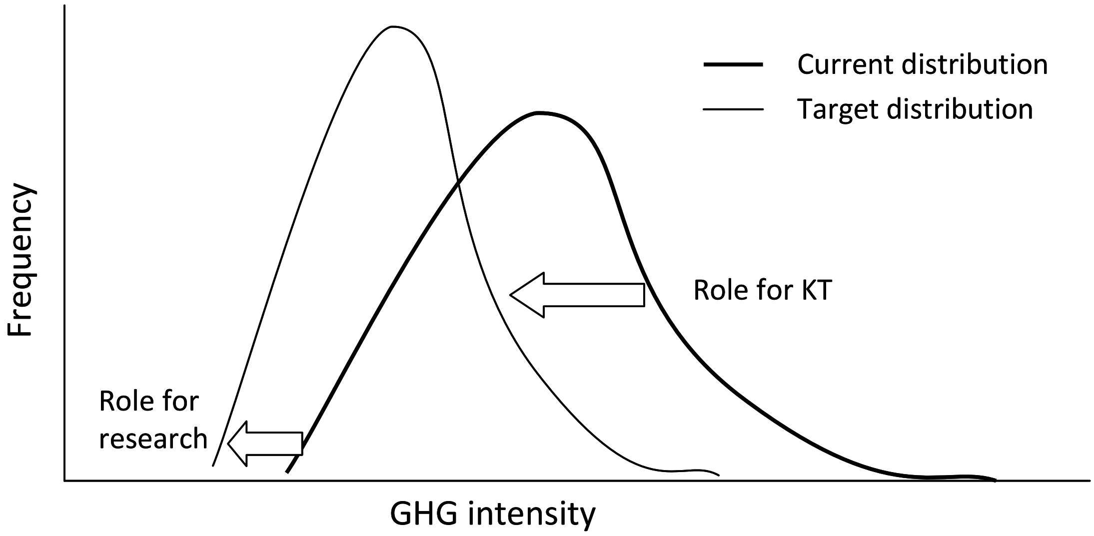


Figure 4.6: Conceptual illustration of the roles of research and KT in reducing the carbon intensity of produce: while new research outcomes can further reduce the minimum carbon-footprint of produce, the role of KT programmes is to narrow the frequency distribution and lower the average GHG intensity, by bringing the carbon intensity of the majority of producer closer to that of the top 10% most efficient producers.

Therefore, the full potential of Pathway B can only be realised if it is supported by a comprehensive KT programme. This finding concurs with one of the main recommendations of the Environmental Analysis of the Food Harvest 2020 Strategy (Farrelly *et al*., 2013), commissioned by DAFM.

In response to this KT challenge, and since the publication of our MACC report, Teagasc and Bord Bia have jointly developed the Farm Carbon Navigator, an on-farm KT tool to aid farmers and advisors in selecting cost-effective / cost-beneficial mitigation options that are customised for their individual farming system and environment. Textbox 4.3 provides details of the Farm Carbon-Navigator, as published by Murphy (2012).

Text box 4.3: The Farm Carbon Navigator (source: Murphy, 2012)
The Farm Carbon Navigator is being developed as a joint venture between Teagasc and Bord Bia. It is a tool with a simple objective and *modus operandi*. It is designed to assess the level of adoption of technologies that have been proven to reduce GHG emissions on farms, to communicate with the farmer how he/she is performing and to give clear targets for improvement. The Farm Carbon Navigator does not provide an overall count of GHG emissions on the farm as to do that would be expensive and make it too cumbersome and bureaucratic to be an effective tool at farm level. Moreover, the objective is to set emissions on a downward path rather than to accurately estimate emissions; the latter task is a research rather than KT subject, which can be pursued more efficiently through surveys such as the Teagasc National Farm Survey. Instead, the Farm Carbon Navigator focuses on 'distance to target' by assessing current performance, comparing that performance with average and best performing farmers and setting practice adoption and efficiency targets to be achieved over a three-year period.

The Farm Carbon Navigator will be delivered in conjunction with Bord Bia Quality Assurance Schemes. The Quality Assurance Schemes are independently accredited national schemes for beef and lamb production in Ireland. An equivalent scheme for dairy production is in development. The Beef Quality Assurance (QA) Scheme currently has approximately 32,000 participants, which are audited at least once every 18 months. It involves data gathering by QA inspectors and links to other data sources, such as the Department of Agriculture, Food and the Marine and the Irish Cattle Breeding Federation. This database provides an efficient and effective platform for the navigator given that most of the data required to deliver the outputs of the model are already in the database. A relatively small amount of data entry by farmers, or their advisers, will allow the model to be run.

How it works
The first Farm Carbon Navigator has been developed for beef farmers and this will be quickly followed by a version for dairy farmers. The model will focus on six technologies at farm level. It does not cover all potential mitigating technologies but focuses on ones that meet the following criteria:
• There is a body of science to support and quantify the mitigation capability of the technology
• It is relatively easy to implement at farm level
• It has a significant impact on GHG emissions
• It is cost-effective
The design of the programme will allow additional measures to be included at a later stage.

The Farm Carbon Navigator assesses the farmers' current performance with respect to six technologies. These are:
• Grazing season length – Longer grazing season reduces rumen methane production and reduces storage period and losses associated with manure application
• Calving rate – Higher output per cow and hence more produce for the same amount of greenhouse gas
• Age at first calving – Shorter, unproductive time thereby lowering emissions
• Liveweight gain – Higher output and/or faster finishing times and hence more meat for the same amount of greenhouse gas
• Nitrogen usage – Lowering of nitrogen usage per kg output
• Slurry application – Lowering GHG losses through timing of application and application method.
Each technology is assessed and a common approach is used to present the information. The objective of the output is to let the farmer see that by improving performance or adopting a technology he/she can both reduce GHGs and also increase the profitability of the enterprise.

The system outputs are graphic rather than textual and include:
• Details on current performance
• A rating of the current performance compared to average and top 10% performance in the farmer's own region/soil
• The target for future performance
• The financial impact of achieving the targets
• An explanation of how the performance improvement reduces GHG emissions.

4.3.4 Pathway B: Multi-criteria assessment

The multi-criteria assessment for Pathway B is listed in Table 4.2:

Table 4.2: multi-criteria assessment for Pathway B	
Consideration	**Assessment**
Impact on farm profitability / rural economy	Depends on the menu of measures that is deployed. Many of the measures that relate to farm and resource use efficiency are cost-beneficial and represent a win:win opportunity as they yield financial as well as environmental rewards. However, some of the measures are currently cost-prohibitive and their employment could reduce farm profitability. Examples of these include the use of low-emission slurry spreading equipment, anaerobic digestion of pig slurry and the current generation of nitrification inhibitors. It is worth noting that, in many cases, the cost-effectiveness of measures depends on a combination of economic farm parameters and can therefore be subject to future change. In other words: measures that are currently cost-prohibitive may become cost-effective in future or *vice versa*.
Impact on global agricultural GHG emissions	Depends on the menu of measures that is deployed. Cost-beneficial measures relating to higher resource use efficiency should not result in carbon-leakage and therefore contribute to a reduction in global GHG emissions. However, the deployment of cost-prohibitive measures (for example, in a 'Sustainable but Short' scenario – *cf*. Section 2.3.2) could potentially lead to reduced competitiveness and carbon leakage to other jurisdictions / farming systems with a higher carbon footprint.
Competition for land / land availability	Pathway B does not involve land use change and therefore is unlikely to results in competition for land or be associated with constrained land availability.

<table>
<tr>
<td>Potential impact on other aspects of environmental sustainability</td>
<td>Largely positive, but with potential for negative side effects.
For the measures included in the MACC, our second report listed the potential interactions with other aspects of environmental sustainability (Table 3.1 in Schulte & Donnellan, 2012):
Indicative potential impact of each of the GHG abatement measures on environmental variables. Note: ✓ indicates reduced environmental risk, x indicates potential for increased risk.
<table>
<tr><th>Measure</th><th colspan="3">greenhouse gases (LCA)</th><th colspan="4">other environmental variables</th></tr>
<tr><th></th><th>methane</th><th>nitrous oxide</th><th>carbon dioxide</th><th>ammonia</th><th>water quality</th><th>herbicide use</th><th>soil quality</th></tr>
<tr><td>EBI</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Live Weight Gain</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ext grazing</td><td>✓</td><td>✓ or X</td><td>✓</td><td>✓</td><td>X</td><td></td><td>X</td></tr>
<tr><td>Manure management</td><td></td><td>✓ or X</td><td>✓</td><td>✓</td><td></td><td></td><td>X</td></tr>
<tr><td>Nitrification inhibitors</td><td></td><td>✓</td><td></td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td>N-efficiency</td><td></td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td></tr>
<tr><td>Min till</td><td></td><td>X</td><td>✓</td><td></td><td>✓</td><td>X</td><td>✓</td></tr>
<tr><td>Cover crops</td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td><td>X</td><td></td></tr>
<tr><td>Bio-energy crops</td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td>Biofuel crops</td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sugar beet for ethanol</td><td></td><td>✓</td><td>✓</td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td>AD (pig slurry)</td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td><td></td><td></td></tr>
</table>
Since Pathway B relies partially on technological interventions, some of the measures currently being researched (Figure 4.2) may face opposition and be the subject of controversy. Examples include the development of GMO crop varieties and the development of methanogen vaccines for bovine (see e.g. Garnett, 2008).</td>
</tr>
<tr>
<td>Resilience of pathway to climate change</td>
<td>We expect that Pathway B will have a mixed resilience to climate change. Some measures are likely to be more sensitive (e.g. extended grazing) to climate change than others (e.g. sexed semen).
As individual measures are likely to show different responses to changes in climatic variables, any suite of measures should be more resilient than its individual components.</td>
</tr>
</table>

4.3.5 Pathway B: Assessment summary

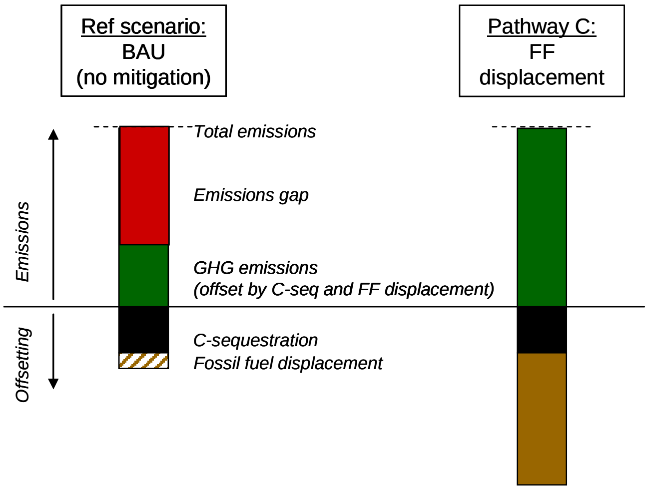
Pathway B is based on reducing the carbon-intensity (carbon footprint) of agricultural produce, with the ultimate goal of reducing GHG emissions while increasing, or at least not reducing output. The MACC report (Schulte & Donnellan, 2012) lists the efficacy and cost-effectiveness of measures delivered by a 10-year research programme. Further measures can be expected to be added to future iterations of the MACC, as new research findings come available between now and 2050.

At this point it is impossible to predict the total mitigation potential of the suite of measures currently subject to research, or the timeframes over which new measures will come available. This is a direct result of the very nature of strategic research where outcomes are uncertain. However, given the successes to date, and given the measures that are 'close to market', Pathway B is likely to provide significant scope to reduce the emissions gap from agriculture, and thus bring the targets for the other pathways, specifically A and C, closer within reach.

All measures should be carefully evaluated for cost-effectiveness. In addition and specifically in this Pathway, hard societal choices may be required between reducing greenhouse gas emissions from agriculture, and other aspects of sustainability. Proponents of GMOs may see this as further enhancing the argument for the adoption of GMO technologies in the EU, while opponents of GMOs may need to include any new beneficial impacts of GMOs in their assessment of arguments against their deployment.

Full realisation of the mitigation potential of Pathway B requires a comprehensive KT programme that aids farmers and advisors in customising the mitigation options for their individual farms and biophysical environment. There is significant potential to narrow the frequency distribution of carbon (and resource) efficiency between individual farms, i.e. bring the carbon-intensity of the majority of farms closer to the top 10% most efficient producers, acknowledging for constraints relating to soil types and farming system. The Teagasc – Bord Bia Farm Carbon Navigator is a comprehensive tool to facilitate such a KT programme.

4.4 Pathway C: Fossil fuel displacement



4.4.1 Pathway C: Narrative

The 'fossil fuel displacement' Pathway focuses on the production of bioenergy from bioenergy crops and / or anaerobic digestion (AD) of grass and slurry. This pathway is cross-sectoral in that the bioenergy produced will displace the use of fossil fuels in the energy sector. Within this pathway, we consider two options:

1. Production of bioenergy crops, i.e. Miscanthus and willow
2. AD of mixtures of grass and slurry for energy production.

We do not consider the cultivation of food-crop based biofuels (i.e. for production of liquid biofuels) within this pathway. The cultivation of biofuel crops is in direct competition with food production. For this reason, the EU has recently revised its policy on biofuels, capping its use in transport fuel mixes to 5.5%, citing increased food prices and inadvertent land use change as reasons for this decision. Therefore our analysis here focuses on bioenergy crops and grass as feedstocks for energy generation, for which the risk of direct competition with food production is potentially lower (see section 4.4.4: contextual considerations).

At this point it is not clear to what extent fossil fuel displacement is eligible for use as a mechanism to offset agricultural emissions in the quest towards carbon neutrality. The NESC report proposes 'full and permanent decarbonisation' of Ireland's energy sector by 2050, equating to a zero reliance on fossil fuels. If bioenergy production is 'credited' to the agricultural sector, this could be considered as 'double accounting' of the benefits arising from bioenergy production, i.e. it would be counted in both the balance sheets of 'carbon-neutrality' for agriculture and 'full decarbonisation' of the energy sector. However, these uncertainties surrounding the accounting mechanism should not stop us from exploring the potential of bioenergy crops and AD in reducing the national (cross-sectoral) GHG balance sheet.

Bioenergy crops

A number of supply chains are conceivable for energy crops:

1. A farmer produces biomass which is sold to a merchant. The merchant sells the biomass to an end-user in the heat or electricity market.
2. A group of farmers form a co-operative or user group which manages the biomass produced by the farmer group, selling it on to an end user.
3. The farmer sells directly to an end-user in the heat or electricity market.

Supply chains will of necessity be short (e.g. less than 50 km) as a result of the economic costs associated with the transportation of biomass with low bulk density. This, it is most likely that the most significant supply chains will develop in areas of high demand. However, smaller supply chains, perhaps with as little as one producer and one consumer could potentially develop in any part of the country. It is possible that some farmers may develop into specialist biomass producers, much will depend on the relative difference between the profitability of biomass production and that of other agricultural activities.

AD of grass

Two supply chains are conceivable for AD of grass:

1. A farmer produces and sells grass/silage to an AD business. This means that he/she is a grassland farmer producing/selling a commodity called grass.
2. A farmer invests in an AD facility on his/her farm then he/she is an energy provider (electricity/heat or biogas/biomethane) who uses grass silage as their feedstock.

In practice, there may be a combination of centralised and some on-farm systems. However, the major biogas/biomethane yield may well come from centralised systems where either business or groups of farmers come together to (a) get some scale (and facilitate the investment of upgrading the biogas to biomethane) and (b) position on the gas grid for injection of biomethane so it can be used as a transport fuel. In such a case there might be a network of specialised farms providing grass (via silage) in a catchment area. They would likely use best technologies to produce high yields of appropriate quality grass. It is likely that advances in fibrolytic enzyme technologies in the coming decades will mean that we can 'pre-treat' the herbage during ensilage in order to increase the yield of methane produced from the herbage.

4.4.2 Pathway C: Technical description

Bioenergy crops

Both the cultivation of bioenergy crops and AD of grass are in their infancy in Ireland. The area under energy crop cultivation (Miscanthus, willow) is currently estimated at *c*. 3,600 hectares, equating to less than 1% of the national tillage area, while in 2010 there were only four on-farm anaerobic slurry digesters in the country (Smyth *et al.*, 2010). Technically, however, bioenergy crops and AD have significant potential to reduce the national reliance on fossil fuels by replacing the thermal energy demand (coal, oil, gas, peat), as well as the electricity demand.

Currently, no projections are available for energy demand in 2050, the closest projections being the forecast for 2020 by the Sustainable Energy Authority of Ireland (Clancy & Sheer, 2011). These show a gradual decrease in energy demand due to increased efficiencies. In the absence of energy demand projections for 2050, we used these 2020 figures instead. If – in a hypothetical scenario – all of the thermal energy demand and electricity demand generated by peat were to be replaced by bioenergy crops, this would result in a significant reduction in the national GHG inventory by *c*. 11Mt CO_2eq. However, to meet the associated demand for feedstock, this would require the planting and cultivation of bioenergy crops on 0.9 million hectares. While there is scope to increase the areal extent of bioenergy cultivation – starting from its current low base – this would represent a 300-fold increase in area, which is unlikely to materialise, even over the timespan up to 2050. Previously, for the generation of our MACC for Irish agriculture (Schulte & Donnellan, 2012), we assumed that by 2020 the area of willow and Miscanthus cultivation could increase to a maximum of 50,000 hectares.

AD of grass

Alternatively, a significant proportion of the thermal energy demand could be replaced by AD of grass / slurry mixtures. Biogas produced from anaerobic digestion can be used for a range of purposes including electricity and heat generation. When it is upgraded to biomethane (>97% methane content) it may be injected into, and distributed, by the natural gas network. Biomethane has been highlighted by the EU Renewable Energy Directive to be a sustainable transport biofuel.

Wall *et al*. (2013) in laboratory assessment highlighted that 1 kg of organic matter can produce 308 l of methane, using a 1:1 volatile solid ratio (or 1:4 volumetric basis) of grass and slurry. This equates to a potential gross energy production of 235 GJ per hectare per annum. This is significantly higher than that of rape seed biodiesel (44 GJ ha^{-1} yr^{-1}) or wheat ethanol (66 GJ ha^{-1} yr^{-1}) (Smyth *et al*. 2009).

In calculating the GHG mitigating effect of biogas or biomethane, the end use (thermal, electricity, transport biofuel) and the fossil fuel displaced (e.g. diesel or natural gas) has a significant impact on the result. In assessing the sustainability of grass biomethane as a transport biofuel, Korres *et al*. (2010) highlighted that a 60% reduction in GHG emissions in displacing diesel on a whole life cycle basis can be readily achieved.

Assuming this GHG savings with biomethane produced from grass and slurry (at a 1:1 volatile solid ratio) 12.2 t CO2eq per hectare may be saved per year. Thus if – in a hypothetical scenario – the emissions gap (11 Mt) were to be closed with biomethane from grass and slurry this would require the cultivation of 0.9 million hectares of grass a figure identical to the aforementioned area required if the same demand were to be met by cultivation of bioenergy crops alone.

It should be noted that the GHG savings displacing natural gas as a source of renewable thermal energy would be less as natural gas produces less GHG per unit of energy than diesel (53 kg CO_2/GJ versus 76 kg CO_2/GJ in direct combustion).

4.4.3 Pathway C: Constraints

While bioenergy production and AD of grass are technically promising land use options, the uptake to date of these technologies has been very low in Ireland. Here we consider three potential constraints as explanations for this low uptake to date: i) the availability of land, ii) capital investment requirements and iii) the economic/policy/legislative environment.

Availability of land

In order to make a meaningful contribution to the closing of the emissions gap, the cultivation of bioenergy crops and grass for AD will require significant areas of land. Cultivation of either crop would be most appropriate on grassland currently under-utilised for livestock production. This does not necessarily need to result in competition with livestock production, since at national level the current production and utilisation of grass is well below capacity.

At present, annual average surplus grass production is estimated at *c.* 1.67 million tonnes DM over and above livestock requirements, due to sub-optimal utilisation (McEniry *et al.*, 2013). Furthermore, there is significant scope to further increase grass production at national level (see e.g. Schulte *et al.*, 2013). In a hypothetical scenario, where the fertiliser nitrogen application to every hectare of grassland is increased up to the permitted maximum level and where the efficiency of grass utilisation by grazing (on beef/dairy farms; not sheep) is increased from 60 to 80%, the potential grass surplus could increase by a factor of approximately 8 (McEniry *et al.*, 2013). Whilst some of this potential increase in grass production and utilisation will be required to meet the livestock requirements in a Food Harvest 2020 scenario, a significant potential surplus could be available for either silage harvesting for AD of grass or substitution by bioenergy crops.

In general, the availability of land is unlikely to be the main constraint to the cultivation of bioenergy crops or grass for AD up to a point. However, providing 900,000 ha to mitigate a substantial proportion of agricultural GHG emissions in 2050 would provide a significant challenge for Irish agriculture. However, it would likely be a limitation in some regions (where demand for grass as a feed for livestock was high) and on some occasions (e.g. if weather conditions caused problems with grass production for or utilisation by livestock).

Capital investment

Significant capital investments are required for the processing of the feedstock. For energy crops, the most significant item of capital expenditure will be that of drying, storage and handling facilities for biomass. Furthermore, large investments in drying facilities would be required to dry willow chips to a moisture content that would be suitable for combustion in most boilers. Additionally, significant storage facilities would be needed to store very large quantities of low density fuels such as willow chips and miscanthus chips

Capital costs of AD units are estimated at €1.8 millions for a 250 kWe unit and €3.5 million for a 500 kWe unit; at present most on-farm units would be within this size range (B. Caslin, pers. comm.).

Economic/policy/legislative environment

Growth to date in the bioenergy industry has been slow and a number of initiatives need to be put in place before significant growth can occur in the bioenergy industry. Such initiatives include:

- Strong and clear policy on bioenergy is needed to provide the confidence needed for farmers and investors to enter the bioenergy industry.
- Policy on bioenergy needs to embrace all relevant government departments and public bodies which can contribute to the policy.
- The complex planning, licensing and consents environment needs to be addressed and bureaucratic obstacles need to be eliminated.
- The current financing environment is difficult with indigenous banks restricting lending and foreign lenders being nervous about lending into Ireland.
- Electricity tariffs need to be pitched at the correct level to stimulate on farm investment in anaerobic digestion.
- Renewable heat incentive targets are necessary to stimulate ingress of bioenergy into the heat market.
- Grid connection costs should be both standardised and minimised. Grid prioritisation should be given to biomass projects which provide a continuous and reliable energy supply.
- Incentives are needed to promote the use of biomethane in captive fleets
- Infrastructural supports are needed to incentivise the development of sustainable supply chains.

4.4.4 Pathway C: Multi-criteria assessment

The multi-criteria assessment for Pathway C is listed in Table 4.3:

Table 4.3: Multi-criteria assessment for Pathway C	
Consideration	**Assessment**
Impact on farm profitability / rural economy	Our analysis of bioenergy production for the MACC report (Schulte & Donnellan, 2012) suggests that partial conversion from livestock to bioenergy production is currently cost neutral. In other words, there is currently no financial incentive for farmers to consider conversion, which is compounded by the risks for landowners associated with the requirement for large capital investments. The lack of incentive is partially a reflection of the economic/policy/legislative constraints, low electricity tariffs and small economies of scale. Higher financial returns may be expected with better economies of scale arising from changes in the economic/policy/legislative environment.
Impact on global agricultural GHG emissions	Pathway C is not expected to result in carbon-leakage or increased global GHG emissions, given the potential surplus of biomass (Section 4.4.3). However, double-accounting of credits between the agricultural and energy sectors are a concern.
Competition for land / land availability	Nationally, grass production is well below its biophysical potential. In principle, it is possible to increase grass production to facilitate both livestock production and either grass production for AD or conversion to bioenergy crops (see Section 4.4.3).
Potential impact on other aspects of environmental sustainability	Willow, miscanthus and grass are all permanent crops that make efficient use of inputs and do not require large inputs of herbicides or pesticides. Therefore, the environmental impact of bioenergy / grass for AD cultivations *per se* is expected to be low. However, if a significant expansion in the area of bioenergy crop cultivation or grass for AD is to take place *alongside* the projected expansion in the production of the main agricultural commodities, then this will result in a net intensification of agriculture at national level. This may manifest itself in higher total fertiliser inputs, or intensification of grassland that is currently considered marginal. This in turn may have impacts on greenhouse gas emissions (through increased N_2O emissions), water quality (increased nutrient pressures) and biodiversity (conversion of semi-natural grasslands into productive grassland).

Resilience of pathway to climate change	Miscanthus and grass are permanent crops with long growing seasons and low incidences of pests / diseases. For willow, disease pressures exist depending on clonal variety. For energy generation, the annual biomass production is more important than the seasonal production patterns. This also holds for the AD of grass, since this will be conserved as silage in a number of harvests per year. Therefore temporary reductions in growth rates caused by weather factors are unlikely to impact significantly on energy generation. Therefore the impact of climate change on this pathway is likely to be relatively low, but not insignificant in the case of willow.

4.4.1 Pathway C: Assessment summary

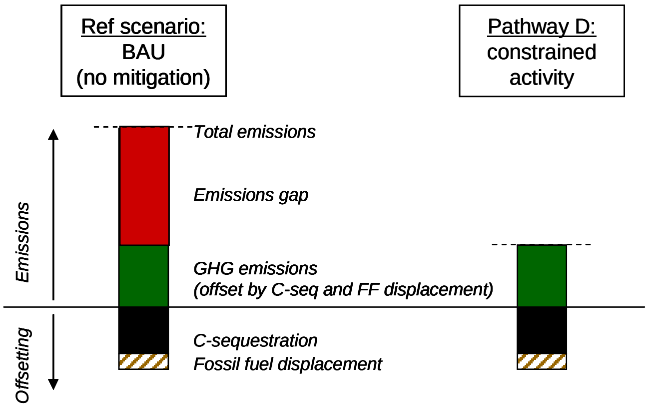
Pathway C is unlikely to close the emissions gap on its own, as this would require an area of 0.9 million hectares to be dedicated exclusively to the production of bioenergy crops and grass for AD, as well as unprecedented capital investments in the post-farm infrastructure for energy generation.

However, there is a realistic potential for pathway C to contribute to the closing of the emissions gap; existing technologies continue to achieve incrementally higher conversion efficiencies. At national level, there is a real potential to increase total biomass production and utilisation. As a result, a significant increase in the production of bioenergy crops or grass for AD could be achieved without undue competition with food production or the Food Harvest 2020 objectives.

The main obstacles to materialising the potential of Pathway C consist of economic, policy and legislative constraints, rather than technology or the availability of land. The rules governing the regulatory environment within which biogas producers and users operate should facilitate sustainable development, and need to be freely accessible to producers, users and the general public. They should be in harmony with the intent of comparable regulatory systems in other EU countries. Potential examples include a directory of feedstocks that can be used for AD, indicating any restrictions on their use or on the landspreading of the subsequent digestate – ideally, this would be an EU rather than a national directory. In addition, incentivisation of Pathway C requires a mechanism needs to be put in place whereby biomethane can be publicly traded via the national gas grid so that a biomethane producer can input product into the NGG and sell it to someone who wants to purchase biomethane.

Finally, from an administrative point of view we have to consider the risk of 'double-accounting' of carbon credits with the energy sector in this pathway. If bioenergy production can be counted by the energy sector in meeting its target of full decarbonisation by 2050, then it is unclear to what extent bioenergy production can at the same time be counted as an offsetting mechanism for agriculture to close its emissions gap.

4.5 Pathway D: Constrained Production Activity



4.5.1 Pathway D: Narrative

The 'constrained production activity' Pathway focuses on the strong correlation between bovine livestock numbers and GHG emissions. Approximately half of Ireland's agricultural GHG consist of methane emissions from enteric fermentation in bovines, which is a process that is notoriously difficult to mitigate against. Therefore, this pathway, which has been frequently discussed in the public domain, aims at a reduction in bovine livestock numbers, through either:

1. Widespread extensification of production and promotion of low-intensity livestock farming systems, including (but not exclusively) organic livestock systems, resulting in lower GHG emissions per hectare of land and, *ceteris paribus*, lower national emissions;
2. A significant change in livestock production systems, from ruminant farming to mono-gastric production systems, e.g. pigs and poultry, which are not associated with methane emissions from enteric fermentation;
3. A reduction in food waste at household level, specifically waste of livestock produce, resulting in a reduced production requirements per unit of produce consumption

This pathway envisages that changes in the production of food are driven by changes in consumption patterns and consumer behaviour (see e.g. Garnett, 2010 for a review of options), with the latter being partially driven by policy incentives.

In a recent paper (Donnellan *et al*., 2013), we tested the relationship between agricultural production levels and GHG emissions at national level, using an economic scenario analysis that assessed the changes in livestock production patterns required to achieve a (modest) 10% reduction in agricultural GHG emissions by 2050, in absence of any mitigation (i.e. using Pathway D only). In this modelling study, the activity of the sector with the highest ratio of GHG emissions per unit of economic profitability was constrained, in this case the suckler beef sector. The results of this study showed that an 88% reduction in suckler cow numbers compared to the reference scenario (or a 93% reduction compared to 2005) would be required to achieve a 10% reduction in national agricultural emissions (Figure 4.7). This reduction from 0.68 million head under the reference scenario to 0.08 million under the 10% reduction scenario would effectively imply the cessation of suckler beef production systems in Ireland and translate into a reduction in economic value of the total cattle output from a projected €3.6 billion in 2050 under the reference scenario to just €1.4 billion, an annual shortfall in the value of output of €2.2 billion.

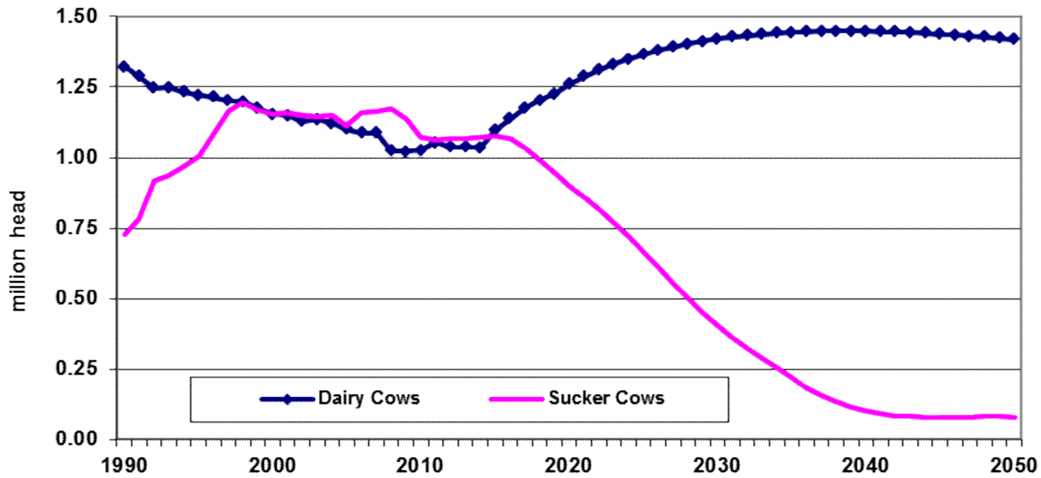


Figure 4.7: Dairy cow and Suckler cow populations in a 10% GHG reduction scenario following Pathway D. See Figure 3.1 for the reference scenario. Source: Donnellan et al*. (2013)*

In Section 3, we estimated the emissions gap by 2050 at *circa* 75% of total agricultural emissions. In the current study we did not test the implications of fully closing this gap using Pathway D alone, i.e. by constraining agricultural activity. Considering the findings above that a 10% reduction in GHG emissions would result in cessation of the suckler beef industry if driven from an economic perspective, the implications of a 75% reduction in GHG emissions through Pathway D alone would almost certainly have draconian consequences for the agricultural industry as a whole.

4.5.2 Pathway D: Technical description

At national level, total agricultural GHG emissions have historically been closely correlated to total bovine numbers, as illustrated in Figure 3.2, albeit that continuing gains in efficiency have led to a degree of decoupling between the two parameters over the last decade. Enteric methane emissions account for approximately half of total agricultural emissions. Therefore, it is widely accepted that GHG emissions *per unit area* are closely linked to livestock densities (see e.g. Casey & Holden, 2005 or data on Irish dairy systems and Clarke *et al*., 2013 for Irish beef systems).

The role of farming intensity / livestock density
However, in the context of the twin challenges of food security and climate change, the GHG emissions per unit product are of greater importance than the GHG per unit area. In this context, three studies comparing organic and conventional dairy systems in Denmark (Kristensen *et al.*, 2011), the Netherlands (Thomassen *et al.*, 2008) and Ireland (Casey & Holden, 2005) all concluded that there is no significant difference in the carbon-intensity of dairy produce from either production system. For suckler beef systems, Casey & Holden (2006) found lower carbon-intensities in produce from organic systems and from systems participating in agri-environmental schemes compared to conventional production systems. In contrast, Clarke *et al*. (2013) found that the carbon intensity of suckler bred beef is similar at higher stocking intensities when compared to more extensive systems. Furthermore, the four studies comparing organic with conventional production systems noted higher land requirements per unit produce for organic systems.

The role of produce type
More pronounced differences in carbon-intensity arise between types of livestock produce, specifically between ruminant produce (e.g. beef, lamb) and mono-gastric produce (e.g. pork, poultry). A comprehensive report by the European Commission (Leip *et al.*, 2010) assessed the carbon footprints of beef, sheep and goat meat, pork and poultry across the EU and found that – on average – the footprints of pork and poultry are approximately three and four times smaller, respectively, than the footprints of beef and sheep and goat meat. These differences were attributed to significantly smaller methane and nitrous oxide emissions associated with mono-gastric livestock production systems.

For dairy, the carbon footprint of milk is much lower per kg produce than is the case for beef, but a direct comparison with the carbon footprint of meat is meaningless due to differences in product composition and nutritional value. Comparing like with like, Smedman *et al*. (2010) contrasted the ratio between the nutritional value of milk (using the Nordic Nutrition Recommendations for 21 essential nutrients) and the GHG footprint, with the equivalent ratios of other beverages (carbonated water, soft drink, beer, red wine, oat drink, orange juice and soy drink). They found that this 'Nutrient Density to Climate Impact Index' was highest for milk – more than twice as high as the second ranking product (soy drink).

The role of consumer choices
Pathway D is closely linked to, and dependent on, consumption patterns of livestock produce. These consumption patterns are not inviolable and change through time, being influenced by relative prices (the price of one meat relative to another or the price of meat relative to rice or other stable grains), real income levels and consumer preferences, all of which tend to change, especially as the time horizon extends. Westhoek *et al*. (2011) estimate that protein intake in developed countries is on average 70% in excess of the levels recommended by the WHO. Food consumption patterns can therefore not be divorced from efforts to find solutions to the global twin challenges of food security and climate change (see e.g. Garnett, 2010). The 'best-of-both-worlds' scenario for Sustainable Food Security (cf.

Section 2.3.2) therefore necessitates changes to both the production and consumption of food. This is supported by a recent paper by Bellarby *et al*. (2013): assessing a variety of high-level options to reduce GHG emissions from agriculture in Europe, this study found that a reduction in the consumption of European-produced beef by 106-149 g per European per week would result in total savings of 67-94 Mt CO_2eq from European agriculture per year. The study concludes that "a reduction in food waste and consumption of livestock products linked with reduced production, are the most effective mitigation options …".

4.5.3 Pathway D: Constraints

Dependency on global consumption patterns

The main constraint to the potential effectiveness of Pathway D in reducing agricultural GHG emissions is that it is inextricably based on a hypothetical reduction in the global consumption of and demand for livestock produce. Irish agriculture is largely based on exports: 90% of beef produce, 80% of milk and 50% of sheep/lamb produce is exported to other jurisdictions. This means that changes in *domestic* consumption patterns will have a disproportionally small impact on the overall demand for these products and that the effectiveness of Pathway D relies on changes in *global* consumption. FAO projections (Alexandratos & Bruinsma, 2012) suggest an inverse future pattern in global demand, instead: a 60% increase in the demand for food between 2005 and 2050, and an even sharper increase (almost doubling) in demand for livestock produce, mainly driven by increasing levels of affluence in the emerging economies.

Management of global consumption patterns: a knowledge vacuum

While it is increasingly acknowledged that solutions to the global twin challenges of food security and climate change are likely to necessitate consideration of the current overconsumption of livestock produce in developed countries, it is yet unclear how consumption patterns can be influenced equitably, especially at global scale. Mechanisms that have been proposed include carbon pricing of food products (i.e. including a carbon-tax based on 'embedded emissions'; see e.g. Garnett, 2008), but is unclear how to negate the potential undesired side-effects of carbon pricing, e.g. an inequitably asymmetric impact on food choices. Put simply, carbon-pricing of carbon-intensive food items is likely to affect poorer households more than wealthier households, leaving poorer households disproportionally restricted in their food choices. In 2011, Denmark pioneered a 'fat-tax' on produce containing more than 2.3% saturated fat that included dairy produce, meat and processed foods (citing public health drivers rather than greenhouse gas emissions). However, this tax was abolished in 2012 amongst concerns that the tax had resulted in higher food prices and cross-border purchases (see e.g. http://www.bbc.co.uk/news/world-europe-20280863).[1]

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[1] In November 2014, Teagasc and the RDS will be hosting a lecture on the subject of "How can we change food consumption patterns?" as part of the Teagasc & RDS Public Lecture Series 2012-2014 (see http://www.teagasc.ie/events/rds-lecture-series/programme.asp for details).

Risk of carbon-leakage

In absence of reduced global demand, and in the presence of a more likely increase in global demand for livestock produce, pathway D is associated with significant risks of carbon leakage. This was discussed in detail in our first report (Schulte & Lanigan, 2011) and in studies by O'Brien *et al*., (2012a, 2012b) (see also Section 1.1.2 of the current report). In brief, the carbon footprint of Irish livestock produce is low compared to livestock produce from other parts of the world. An FAO (2010) comparison of production systems at global level showed that the carbon footprint for dairy is lowest in 'temperate grassland-based production systems'. A subsequent study by the European Commission's Joint Research Centre (Leip *et al*., 2010) compared the carbon intensity of livestock produce across EU member states and found that Ireland has the lowest carbon footprint for milk and the fifth lowest footprint for beef.

A unilateral reduction in meat production from Irish agriculture in the face of growing global demand for livestock produce is likely to be substituted by increased production of livestock in other jurisdictions or regions of the world. Given the favourable ranking of Irish agriculture in terms of carbon-efficiency, there is a significant risk that substitution will take place in farming systems with a higher carbon-footprint. The net result of this 'carbon leakage' will be a reduction in national (Irish) GHG emissions from agriculture, but a concomitant *increase* in global GHG emissions from agriculture.

The same risks apply in a wider context to the concept of extensification of agriculture. In a comprehensive assessment of UK agriculture, Glendining *et al.* (2009) studied the environmental costs associated with beef and lamb production as a function of farming intensity (using nitrogen input as a proxy indicator). They found that the direct environmental costs per unit produce (arising from losses of pesticides, nutrients, N_2O and other GHGs) increased almost linearly with farm intensity. However, when taking into account the additional land area required for more extensive production of livestock produce, the outcomes reversed: the most extensive production systems were associated with the highest environmental costs, due to additional demands on land use, whilst the lowest environmental costs associated with beef and lamb production were found at intensities close to the current farm intensities in the UK.

Finally, even in the unlikely scenario where global demand for livestock produce is reduced by 2050, there are reasons why this should not necessarily result in reduced livestock production in Ireland. Contemporary thinking suggests that a key-ingredient of sustainable food production at global level is that each food type is produced in regions, climates and on soils where it can be produced most efficiently in terms of its impact on resource usage and the environment (e.g. Haygarth & Ritz, 2009; Benton, 2012b; Fresco, 2012). Given the aforementioned low GHG emissions intensity of Irish livestock produce, Irish agriculture would continue to play a key-role in livestock production in an optimised scenario of food demand and supply.

4.5.4 Pathway D: Multi-criteria assessment

The multi-criteria assessment for Pathway D is listed in Table 4.4:

Table 4.4: Multi-criteria assessment for Pathway D	
Consideration	**Assessment**
Impact on farm profitability / rural economy	The impact of Pathway D (in isolation) on the agri-food sector is potentially draconian (see Section 4.5.1).
Impact on global agricultural GHG emissions	Pathway D will only reduce *global* GHG emissions in the unlikely scenario of a reduction in global demand for livestock produce. In a more likely scenario of increased global demand for livestock produce, there is a significant risk that Pathway D will result in an increase in global GHG emissions.
Competition for land / land availability	*Within Ireland*, Pathway D is likely to result in reduced competition for land, due to reduced agricultural activity. At *global* level, there is a significant risk that Pathway D may contribute to land use change in regions outside Ireland (see Section 4.5.3)
Potential impact on other aspects of environmental sustainability	The impact of Pathway D is likely to be positive for other aspects of environmental sustainability, arising from reduced nutrient pressures in an extensification scenario. An alternative scenario based on a substitution of ruminant production with mono-gastric production may increase national imports of feed and embedded nutrients, which may pose challenges to nutrient management at national scale.
Resilience of pathway to climate change	Since Pathway D is based on changes in consumption and reduced agricultural activity, it is unlikely to be sensitive to climate change.

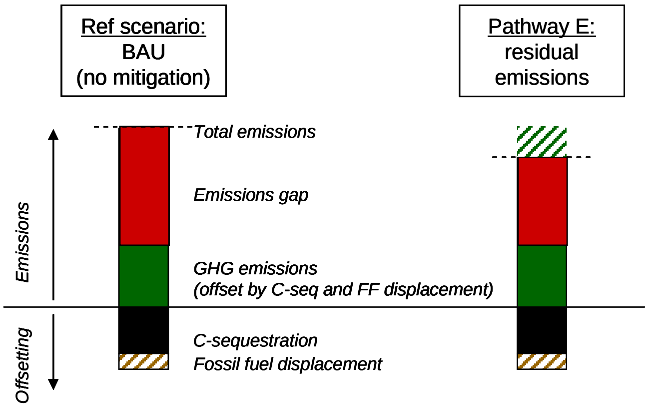
4.5.5 Pathway D: Assessment summary

Pathway D poses a major conundrum to decision makers worldwide. On the one hand, at global scale, inequities in consumption patterns of livestock produce present a major obstacle to meeting the twin challenges of food security and reducing GHG emissions, and it is increasingly acknowledged that future 'sustainable food security' requires that changes to the global patterns of both production *and* consumption of food taken into consideration, in order to progress to a 'best-of-both-worlds' scenario (cf. Section 2.3.2); see Garnett (2010), or Sonnino & Moragues-Faus (2013) for a full review.

However, our assessment also demonstrates that, when applied unilaterally to Irish agriculture, efforts to close the 'emission gap' through Pathway D alone may result in a 'worst-of-both-worlds' scenario (JRC scenario, see Section 2.3.2): in absence of a global reduction in demand for livestock produce, Pathway D is likely to *increase* global GHG emissions from agriculture and at the same time have an adverse economic impact on the agri-food sector.

Finally, it is worth noting that our reference scenario (Section 3) already assumes a significant contraction of the suckler beef sector, driven by a projected gradual erosion of the real value of agricultural subsidies over time.

4.6 Pathway E: Residual emissions



4.6.1 Pathway E: Narrative

The ‘residual emissions’ pathway prioritises the objective of contributing to Sustainable Food Security at a global scale over the objective of reducing national GHG emissions from agriculture *per se*, and is based on a societal acceptance that food production is inherently associated with GHG emissions. In effect, this pathway therefore represents a mirror image of Pathway D. It does not, however, equate to ‘doing nothing’.

Pathway E is based on maximising the resource use efficiency of food production, both at national and global scale. At global scale, this means that each food product is produced in regions, climates and on soils where it can be produced most efficiently, i.e. with maximum ratios of output:land area or output:input (cf. Section 4.5.3). As we have seen in Sections 1.1.2 and 4.5.3, the temperate grass-based farming systems in Ireland are among the most efficient producers of ruminant produce in Europe (Leip *et al.*, 2010), as well as globally (FAO, 2010), especially in terms of GHG-emissions per unit product. Therefore, in Pathway E Irish agriculture positions itself as a leading provider of livestock produce. At national level, efforts are continued to further reduce the carbon-footprint of produce by further gains in production efficiency. In other words: the ‘green measures’ of the MACC, i.e. those based on efficiency, all of which are cost-beneficial, see widespread implementation in a knowledge-intensive agricultural sector.

In Pathway E, full carbon-neutrality of agriculture is not achieved by 2050. It is based on a societal acceptance that food production is associated with GHG emissions. This pathway requires that national climate policies approach agricultural emissions differently from approaches taken to other sectors, for two reasons:

- There are no technological substitutes for food production, whereas there are technological alternatives for power generation, fossil fuel based transport, etc. Put colloquially: there is no ‘electric cow’.
- The challenge of reducing global agricultural emissions is closely linked to, and must be considered within the context of global food security.

Therefore, in this Pathway, agricultural emissions represent the vast majority of residual national emissions by 2050, following full decarbonisation of all other sectors.

4.6.2 Pathway E: Technical description

'Produce locally' versus *'global distribution'*

Pathway E is based on the premise that key to achieving sustainable food security at the global scale is that all food products are produced where they can be produced most efficiently, which requires a degree of global governance of food production (see e.g. Schulte *et al*., 2013). This pathway contrasts sharply with a 'produce locally' narrative, which is frequently discussed in the public domain. The latter narrative proposes that sourcing food locally reduces the embedded transport emissions of food, also know colloquially as 'food miles'. Full reviews on this issue are provided by Garnett (2003), Garnett (2008) and Edwards-Jones *et al*. (2008), with the latter study concluding that "food miles are a poor indicator of the environmental and ethical impacts of food production". In short: the merits of either the 'produce locally' or 'distribute globally' narrative depends on the type of food being considered. For some food products (e.g. greenhouse produced vegetables), transport emissions outweigh marginal differences in production emissions between regions of origin, in which case a 'produce locally' narrative is merited. For most livestock food products, however, emissions associated with transport are small in comparison with both the on-farm level of emissions associated with their production, as well as differences in these emissions levels between regions. In this case, the 'distribute globally' will result in the lowest level of global GHG emissions associated with the production of that foodstuff. An example is provided by the New Zealand study on "Comparative Energy and Greenhouse Gas Emissions of New Zealand's and the UK's Dairy Industry" by Saunders & Barber (2007), which found that the energy intensity (and GHG intensity) of New Zealand produced milk solids was significantly lower than the equivalent of UK produced milk, even when accounting for shipping of the milk solids from New Zealand to the UK. Critiques of that report are discussed in Garnett (2008).

Smaller reduction targets for agriculture?

The difficulties that are uniquely associated with reducing agricultural emissions are already increasingly recognised in national and international policy documents. For example, the European Climate Foundation's scenario analysis for Europe's emissions profile by 2050, presented at the NESC / EPA workshop in November 2012 (Brookes, 2012) suggests a 20% reduction in GHG emissions from European agriculture by 2050 against a background of a total cross-sectoral reduction target of 80%, resulting in above-average GHG reductions for other sectors such as power generation. This is in line with the sectoral target in the Swedish roadmap towards carbon-neutrality by 2050, in which agricultural emissions are subject to only a minimum reduction (Hedlund, 2012).

In Ireland, too, the reduction targets proposed for agriculture are below the cross-sectoral average. At the aforementioned NESC / EPA workshop, a 50% reduction target was suggested by O'Reilly (2012), based on the Irish TIMES model (Ó'Gallachóir *et al*., 2012): this target is well below the proposed 80-95% cross-sectoral reduction target for 2050, but at the same time significantly higher than the aforementioned targets that have been suggested internationally.

Risk of perverse mitigation measures

Finally, an overemphasis on reducing domestic agricultural emissions (i.e. emissions occurring within country boundaries) could result in 'perverse' GHG mitigation measures, in which direct domestic emissions are substituted with embedded emissions, which are not accounted for in the National Emissions Inventories. We previously provided an example of such a perverse mitigation measure in our first report (Schulte & Lanigan, 2011), in the form of GHG emissions associated with two contrasting dairy production systems, i.e. pasture-based and based on total mixed ration (TMR) (O'Brien *et al*., 2012b). From the perspective of national emissions inventories, the TMR system is associated with lower GHG emissions within country boundaries. However, the total carbon-footprint of this system is higher once the embedded emissions in the imported concentrates are taken into account. In this example, an overemphasis on domestic emissions could ultimately result in incentivisation of the TMR system, and hence increased carbon-intensity of production.

4.6.3 Pathway E: Constraints

Dependency on global governance of food production

Whilst the approach of 'producing food where it can be produced most efficiently' holds merit in terms of its *technical* potential to minimise GHG reduction from agriculture globally, there is a knowledge vacuum on how such an approach could be managed and incentivised internationally, similar to the knowledge vacuum on how to govern global food consumption patterns. [2]

Risk of complacency and loss of 'differentiation'

A significant risk associated with Pathway E is that it may either be perceived as, or indeed descend into, a 'doing nothing' scenario that lacks incentives for further gains in agricultural efficiency and reductions in the carbon footprint of agricultural produce. This would contrast sharply with the current perception, held by international retailers and customers, of Irish produce as 'green' and environmentally sustainable. Indeed Bord Bia emphasises the sustainability and low carbon footprint of Irish produce as a unique 'point of differentiation' on international markets, in its 'Origin Green' initiative (www.bordbia.ie/origingreen/). At the same time, other countries around the world are funding and promoting initiatives to enhance the sustainability of their agricultural sectors. In that context Pathway E could introduce complacency in the drive to further improve the sustainability of Irish produce,

[2] In March 2014 Teagasc and the RDS will be hosting a lecture on the subject of "Is Better Global Governance of the Food System the Answer?" as part of the Teagasc & RDS Public Lecture Series 2012-2014 (see http://www.teagasc.ie/events/rds-lecture-series/programme.asp for details)

which could undermine the future validity and viability of Ireland's clean and green 'point of differentiation'.

Increased reduction burdens on other sectors
A second constraint to Pathway E is that it increases the GHG reduction burdens on other sectors of society in the inventory approaches that have hitherto been based on national emission reduction targets. This is exemplified by the cross-sectoral scenario analysis by Ó'Gallachóir *et al*. (2012), using the Irish TIMES model. Their analysis shows that when a cross-sectoral EU emission reduction ambition of 80% by 2050 is relaxed for agriculture to 50%, this would result in an increase in the emission reduction targets for the other non-ETS sectors from 80% to 95% by 2050. Furthermore, if agricultural emissions by 2050 were to remain equal to the projected agricultural emissions for 2020 (i.e. emissions plateau after 2020), then the reduction targets for the other sectors would be in excess of 100%, which would translate into a requirement for carbon capture by these other sectors.

Similar principles apply in the context of the new proposed framework of a 'carbon-neutral' Ireland. Under Pathway E, Irish agriculture does not achieve full carbon neutrality, which implies that either:

1. The Irish economy as a whole does not meet its ambition of carbon-neutrality by 2050;
2. Other sectors of the economy are required to be carbon-negative (e.g. through carbon capture) to compensate for the lack of carbon neutrality of agriculture. (Note that in this context, carbon sequestration through Land Use and Land Use Change has already been accredited to agriculture);
3. The difference is offset through purchase of international 'carbon credits'.

These significant trade-offs between the agricultural sector and other sectors of the economy are more prominent in Ireland than in most other developed countries, as a result of Ireland's unusual emissions profile, which is characterised by a high proportion of emissions arising from agriculture. As discussed previously (Schulte & Laningan, 2011) and in Section 1.1.2, this anomalous profile is not a reflection of a lack of agricultural production efficiencies in respect of emissions per unit output; rather it is a reflection of importance of agriculture to the national economy, the quantity of food produced which is exported to international markets and the historical lack of industry, which 'masks' agricultural emissions in many other developed countries. In those latter countries, any relaxation of reduction targets for the agricultural sector have little impact on the targets of other sectors, due to the small relative proportion of emissions arising from agriculture.

For Ireland, the only way through which these inadvertent trade-offs between agriculture and other sectors can be negated is in a scenario in which the internationally-agreed national emission targets take account of the emissions profiles of individual countries, and less onerous reduction targets are apportioned to countries with a relatively high proportion of agricultural emissions, not unlike the mechanisms through which the EU non-ETS reduction targets for 2020 were differentiated relative to the GDP of Member States.

4.6.4 Pathway E: Multi-criteria assessment

The multi-criteria assessment for Pathway E are listed in Table 4.5:

Table 4.5: Multi-criteria assessment for Pathway D

Consideration	Assessment
Impact on farm profitability / rural economy	Pathway E could have mixed impacts on farm profitability / the rural economy: In the short term, implementation of cost-beneficial measures, and the absence of cost-negative interventions are likely to have a positive impact on farm profitability. In the long term however, any descent towards complacency through Pathway E could undermine the 'sustainability' credentials of Irish produce and its 'point of differentiation' on international markets, with negative impacts on farm profitability
Impact on global agricultural GHG emissions	Pathway E negates any risk of carbon leakage: this translates into a positive marginal impact on global GHG emissions. However, in the event that Pathway E should result in complacency, this could undermine opportunities and efforts towards further reductions in the carbon intensity of Irish produce, translating into a negative marginal impact on global GHG emissions.
Competition for land / land availability	At a global level, Pathway E reduces the potential for competition for land or constraints to land availability, as Pathway E does not require land for full or partial offsetting (through e.g. afforestation) of agricultural emissions. At national level, Pathway E could be associated with a higher competition for land by an expanding agricultural industry with other land uses.
Potential impact on other aspects of environmental sustainability	For other aspects of environmental sustainability, similar principles apply as for GHG emissions: at a global level pathway E negates the 'export' of environmental challenges to production systems elsewhere. At national level, however, it could result in an expansion in both the intensity and geographic extent of intensive livestock production with associated higher pressures on biodiversity and nutrient pressures.
Resilience of pathway to climate change	The resilience of Pathway E to climate change is not expected to be different from the resilience of the Reference Scenario.

4.6.5 Assessment summary

Similar to Pathway D, Pathway E presents a conundrum for decision makers worldwide, albeit from an opposite viewpoint. In the context of meeting the twin challenges of food security and minimising agricultural GHG emissions, there is scientific and technical merit and economic justification in producing food where it can be produced most efficiently. From this perspective, Ireland is indeed well-placed to be a major global provider of sustainable, low-carbon livestock produce, and constraints on productivity and an overemphasis on reducing Ireland's national emissions could result in the 'worst-of-both-worlds' (JRC scenario, see Section 2.3.2): an increase in global GHG emissions associated with food production (cf. Section 4.5.5).

However, there are significant constraints to Pathway E if it were to be the sole Pathway for agriculture towards 2050. The main risk is that it will be perceived as, or descend into, a pathway of complacency, from the perspective of both producers and consumers. This would pose risks to the current validity of the perception of Irish livestock produce as 'green' or 'sustainable', and could hence erode the value of these perceptions as a point of differentiation on international markets.

In addition, Pathway E is not consistent with current international and national policies: it is predicated on some form of global governance of food production, needed to indeed produce each food product where it can be produced efficiently. In the current policy context, Pathway E could increase the proportional burden on other sectors in meeting national objectives, either in the form of emission reduction targets or carbon-neutrality targets.

5. Discussion and conclusions

Having reviewed the pathways identified in section 4, and acknowledging the limitation of exclusively employing one of these pathways, we posit a further alternative approach involving a combined application of the pathway already defined. Limitations and caveats associated with deploying these pathways are identified and discussed, as are some of the challenges that exist in interpreting and defining carbon neutrality. The section concludes with 5 overarching conclusions in relation to the objective of a carbon neutral Irish agriculture by 2050.

5.1 Summary assessment of Pathways

5.1.1 Which Pathway?

We have summarised our assessments of each of the five pathways, discussed in Section 4, in the summary assessment table (Table 5.1) below:

Table 5.1: Summary assessment table of the five pathways

		Pathway				
		A	**B**	**C**	**D**	**E**
Mechanism[a]		O	M	FF	Av	Ac
Potential reduction in 2050 emissions gap		high	?	med	low	low
Relevance to NESC track	*1. 'Strategic and institutional action'*	√	√	√	√	√
	2. 'Exploration and experimentation'		√	√		
	3. 'Design and implement'	√	√			
Marginal impact on[c]	Agri-food sector					
	Global GHG emissions / C-leakage					
	Land availability / competition					
	Other aspects of environmental sustainability					
Resilience of pathway to climate change[b]						
a: O = offsetting, M = mitigation, FF = fossil fuel displacement, Av = emissions avoidance, Ac = emissions acceptance.						
b: Marginal impact: blank = none or unknown; green = known positive; yellow = mixed (i.e. both positive / negative possible); red = known negative.						

From this table, and from the discussions, we come to the following conclusions:

Each of the five pathways has merits and potential in reducing the emissions gap from agriculture by 2050. Specifically Pathways A has significant potential to reduce the emissions gap through offsetting and fossil fuel displacement. The potential of Pathways B, C, D and E is more difficult to establish with confidence.

However, each pathway is associated with potential negative side-effects. These include potential negative impacts on global GHG emissions through carbon-leakage, adverse economic impacts on the agri-food sector, impacts on land availability or impacts on other aspects of environmental sustainability (e.g. biodiversity, water quality, societal aspects surrounding use of GMO crops). For all pathways, the magnitude of these side-effects tend to be correlated to the extent to which each pathway is pursued. In other words: the side-effects are small for the initial and partial implementation of each pathway, but increase as each pathway is pursued to its full extent. Examples include:

1. For Pathway A (Offsetting), there is ample scope for partial implementation without undesired side-effects, but full implementation could result in competition for land and potential negative interactions with conservation concerns;.
2. For Pathway B (Advanced Mitigation), initial implementation of cost-beneficial measures will result in a win:win scenario, but attempts to fully close the emissions gap through Pathway B alone will require implementation of costly measures and impact negatively on competitiveness.
3. For Pathway C (Fossil Fuel Displacement), there is ample scope for partial implementation without undesired side-effects, but full implementation could result in competition for land with potential impacts on other environmental aspects, e.g. biodiversity.
4. For Pathway D (Constrained Production Activity), there is merit in considering the sustainability of global consumption patterns but full and unilateral implementation of this pathway will impact on food security and economic sustainability.
5. For Pathway E (Residual Emissions), there is merit in considering food security concerns in efforts to reduce global GHG emissions, but sole reliance on this pathway is associated with a risk of complacency with regard to the adverse impact of GHG emissions on the global climate.

The implication of this is that the pursuit of *full* carbon neutrality for agriculture may impact negatively on other aspects of sustainability. This includes the economic and social aspects of sustainability, as well as aspects of environmental sustainability such as biodiversity and water quality. In addition, pathways towards carbon neutrality (specifically Pathway B) may include measures and actions that may ethical concerns in the public domain, including animal welfare concerns (e.g. confinement of animals) and/or the use of genetically modified organisms (GMOs). This leads us to the first conclusion:

<u>Conclusion 1: carbon-neutrality as a 2050 horizon point for Irish agriculture must be carefully considered within the wider context of the sustainability, including economic, social and environmental aspects, as well as competing demands for land use, as negative trade-offs are likely to emerge.</u>

This suggests that it is undesirable to rely and focus on any singular pathway to reduce the emissions gap from agriculture. Discussions in the public domain are frequently dominated by the promotion and critique of such singular pathways. The outcomes of our assessment here suggest that the simultaneous pursuit and *partial* implementation of multiple pathways, is more likely to be effective in reducing the emissions gap from agriculture, while minimising potential negative side-effects.

This leads us to introduce Pathway F: a ‘mosaic of pathways’ towards carbon-neutrality, in which all five previous pathways are partially and simultaneously implemented (Figure 5.1):

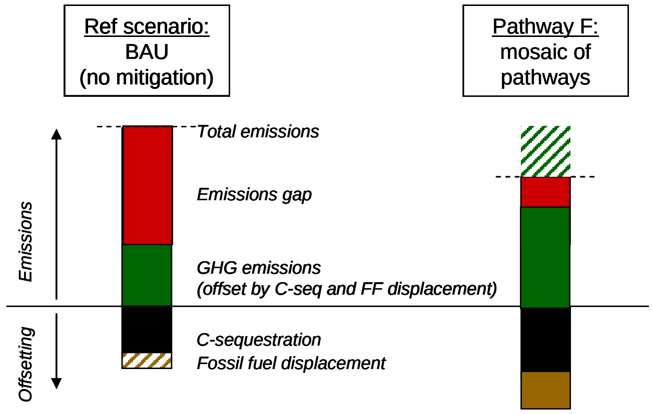


Figure 5.1: Pathway F: a mosaic of pathways.

In our assessment, we come to the following conclusion:

<u>Conclusion 2: simultaneous and partial implementation of all pathways will prove more effective and realistic than reliance on a single pathway.</u>

5.1.2 Is full carbon-neutrality achievable?

Given the uncertainty of policy and market developments over the time horizon to 2050, it is difficult to assess with any certainty at this point whether the emissions gap can be fully closed, so that full carbon-neutrality for agriculture can be achieved. Part of this uncertainty is due to the ‘changing goal posts’ in terms of the cost-effectiveness of individual pathways. One example is the incentivisation of Pathway A through accelerated afforestation. In our previous report (Schulte & Donnellan, 2012), we estimated that the associated costs of incentivising afforestation per Mt of CO_2eq in the form of offsetting would be of the same order of magnitude as the costs associated with purchasing of ‘international carbon credits’, which we estimated (in accordance with SEAI assumptions) at €33 per tonne of CO_2eq by 2020. Since the publication of our last report, the price of international carbon credits has collapsed, due to uncertainties surrounding the international post-Kyoto policy framework. Whilst it is still expected that carbon credit prices are likely to recover, current uncertainties mean that it is not possible at present to make confident projections about the price of carbon credits in 2020, let alone 2050. This has large implications for the economic feasibility and desirability of each of the pathways discussed in our report: at which point is it preferable to purchase carbon credits, as opposed to pursuing domestic pathways? Whilst it is acknowledged that this decision depends on more than the ‘break-even’ price alone (e.g.

potentially higher long-term macro-economic returns from domestic investments than from overseas purchases of carbon credits), there is a point where purchase of carbon-credits internationally becomes a preferable option for Ireland. This is acknowledged by e.g. the Swedish approach to become carbon-neutral by 2050, which includes the purchase of carbon credits to offset 'residual emissions' (Hedlund, 2012).

As the emissions gap is incrementally closed between now and 2050, it will become progressively more difficult to find further solutions and gains in efficiency, in that the 'low-hanging fruit' is likely to be picked first, unless revolutionary scientific breakthroughs change the fundamentals of livestock production. This means that it may prove difficult (or even counterproductive) to achieve *full* carbon-neutrality by 2050.

Notwithstanding the uncertainties surrounding the policy and economic landscapes between now and 2050, an 'early start' on the pathway towards carbon neutrality will be required, specifically in relation to Pathway A, which relies on carbon-sequestration over a period of decades. Unless scope can be created across the policy landscape to facilitate higher levels of forestry sequestration, then the prospect of a carbon neutral agricultural sector in 2050 is at risk. There is still a limited time window in which to create an appropriate environment to produce a substantial forestry sink in the period to 2050. However, without immediate action in respect of the forestry constraints set out in this report, then that opportunity will be lost. It will then become necessary to seriously examine an alternative 2050 ambition for agriculture.

However, such discussions on whether or not full neutrality can be achieved by 2050 should not distract from efforts to minimise the emissions gap, and to approach carbon-neutrality as a horizon point. This leads us to the following conclusion:

Conclusion 3: full carbon-neutrality for agriculture by 2050 may be difficult to achieve, but this should not distract from efforts to approach carbon-neutrality as a horizon point.

5.1.3 Constraints and caveats

It must be noted that each of the pathways, including Pathway F, is associated with significant constraints and caveats, which have been discussed in detail in the individual pathway assessments (Section 4). In summary, these include:

Need for incentivisation

None of the pathways are likely to materialise without some form of incentivisation. Agricultural practices respond to, and are a reflection of contemporary policies and price signals. Whilst (partial) implementation of Pathways A, B, and C may well be cost-beneficial in the long term at national level, their implementation at farm level is currently subject to a variety of constraints, including capital investment requirements and knowledge deficits.

Need for policy interventions
Some of the pathways are subject to additional constraints. The most prominent example is Pathway C; constraints include complex planning, licensing and consents requirements, a challenging financing environment, unfavourable electricity feed-in tariffs and occasionally prohibitively high grid-connection costs. Such obstacles are cross-sectoral in nature and their removal would require cross-sectoral policy interventions.

Need for coherence
Some of the Pathways (specifically Pathways A and C) have potential to result in increased competition for land. Whilst land use in Ireland is currently well below its biophysical carrying capacity (Schulte *et al*., 2013), the efficacy of each of the pathways can be maximised, and potential negative side-effects minimised, through a degree of 'functional land management'. This means that, at national scale, all soils are used to produce the products and services to which they are most suited. The concept of 'functional land management' was first coined by Schulte *et al*. 2013), and is currently the subject of in-depth research by Teagasc and IT-Sligo.

Need for global coherence
Pathways D and E are both constrained by the strong linkages between Irish and global agriculture. Whilst Pathways D and E are to some extent mirror-images of each other, they both rely on achieving a degree of international consensus about the role of agriculture in food security and in combating climate change. The fact that the vast majority of produce from Irish agriculture is exported to external markets means that unilateral policies in Ireland are unlikely to yield tangible results in terms of reducing global greenhouse gas emissions, and could even be counterproductive[3]. The inextricable link between the two 'grand challenges' of Food Security and combating climate change may indeed merit alternative approaches to the global governance of agricultural GHG's, not unlike the separate international arrangements made for GHG emissions from the aviation and maritime sectors.

Uncertainty pre-2050
One of the major challenges of this assessment is taking a view on what will happen in the period to 2050, in the absence of any interventions to address emissions from agriculture. The only real certainty is that, as 2050 is almost 40 year away, the world in 2050 will be very different that the world today. The development of Irish agriculture will be tied heavily to policy decisions taken internationally and market developments which will be determined by global considerations. Therefore, any Business As Usual (BAU) assessment of agriculture will evolve in the period to 2050 will be subject to a wide range of uncertainty. Therefore any

[3] As discussed, in 2014 Teagasc is hosting lectures on options for future global governance of both the production and consumption of food, as part of the Teagasc-RDS Lecture series (see http://www.teagasc.ie/events/rds-lecture-series/programme.asp for details).

decisions that are taken with respect to emissions from the agriculture sector need to be made with these uncertainties in mind.

Uncertainty post-2050

Finally, a major caveat in our assessment is that it extends only to 2050. This is of specific relevance to Pathway A, which relies largely on new afforestation to offset agricultural emissions through carbon-sequestration. Our analysis suggests that higher rates of afforestation may indeed by feasible up to 2050, it is not clear for how much longer such new afforestation rates can be maintained post 2050, before resulting in significant competition for land with other land uses. In addition, our analysis assumes that carbon locked into durable wood products remains sequestered in these products for a period of 100 years (in line with international guidelines). However, on an extremely long time scale (i.e. post 2050), most of the carbon locked into durable wood products will ultimately be released to the atmosphere. From such a 'big picture' perspective, some of the gains arising from Pathway A equate to 'buying time' and the 'temporary' sequestration of carbon. Over such long time frames, it is conceivable that research outcomes may additionally contribute to accelerating carbon sequestration in grasslands in Pathway A, but at this point it is too early to make definitive statements on this subject.

5.1.4 Implications and recommendations

Following the conclusions above, we arrive at the following implications and recommendations, which we have framed in accordance with the three 'tracks' proposed by the NESC Secretariat (2013) (see also Table 5.1).

Track 3 ('Design and implement'):

The efficacy of *modi operandi* of Pathways A and B have been well established: these pathways are therefore ready for implementation.

- Specifically for Pathway A, an 'early start' is essential to maximise its effectiveness, as the carbon offsetting potential of accelerated afforestration by 2050 is disproportionally dependent on the year in which planting rates were first accelerated.
- To aid and begin the implementation of Pathway B, Teagasc and Bord Bia have developed, and are currently deploying, the Farm Carbon Navigator (see Textbox 4.1).

Track 2 ('Explore and experiment'):

This track is of specific relevance to Pathways B and C:

- For Pathway B to achieve its full potential, it relies on a 'conveyor-belt' of research and KT. Whilst the Teagasc MACC and the Teagasc – Bord Bia Farm Carbon Navigator summarise research on cost-effective GHG mitigation measures to date, further advances in reducing the carbon-footprint of agricultural produce relies on continuous investment in and support for research and KT in Pathway B.

- The implementation of Pathway C is currently in its infancy. Pathway C could be implemented in various different forms, e.g. energy crops or AD of grass, decentralised distributed network of producers / processors or large-scale processors linked to the national gas / electricity grid, full conversion and specialisation by a distinct group of farmers or partial conversion by a large group of farmers. Therefore the 'explore and experiment' track appears to be the appropriate approach to implementation of Pathway C, before deciding on the optimal model of operation.

Track 1 ('Strategic and Institutional'):
This track is relevant for all Pathways. Specifically, Pathways A, B and C require national interventions at strategic and institutional level, whereas Pathways D and E require international interventions:

- The implementation of Pathway A (and C) may have implications for land use, which requires a cross-sectoral and cross-enterprise response in terms of the strategic planning of incentivisation mechanisms (see Section 5.1.3). In addition, realisation of Pathway A is reliant on the introduction of site-suitability assessments with a higher resolution that the current 'exclusion zones'.
- Implementation of Pathway B requires not only continued support for research and KT on the mitigation of agricultural GHGs, but may also require a broadening of KT programmes to include all farm advisory services, i.e. including those in the private sector. This is in line with the recommendations by the Environmental Analysis of Food Harvest 2020 (Farrelly *et al*., 2013), and may have institutional implications for e.g. Teagasc itself;
- Implementation of Pathway C requires cross-sectoral policy interventions listed under Section 5.1.3;
- Implementation of Pathways D and E requires coherent international policy interventions on the subjects of international governance of both food production and consumption. Over the last number of years, Ireland has significantly 'punched above its weight' in the international debate on food security and climate change (Meybeck, 2013), and is well placed to continue assuming a leadership role in these discussions.

This three-track approach brings us to our fourth conclusion:

<u>Conclusion 4: A reduction in the agricultural 'emissions gap' by 2050 requires significant and immediate incentivisation programmes, which in turn require cross-sectoral and coherent policy initiatives, both at national and international level.</u>

5.2 How useful is the concept of Carbon-Neutrality for agriculture?

5.2.1 From two to five pathways

In this report, we used the concept and framework of 'carbon neutrality', as defined by the NESC secretariat and as first proposed by O'Reilly *et al.* (2012), to assess options for Irish agriculture to reduce the 'emissions gap' between agricultural GHG emissions and offsetting through carbon sequestration and fossil fuel displacement. This approach towards the accounting and mitigation of agricultural GHG emissions marks a departure from previous approaches which focuses exclusively on reducing agricultural GHG emissions, without accounting for potential offsetting mechanisms.

In our previous report, in which we produced a MACC for Irish agriculture (Schulte & Donnellan, 2012), we showed that the options to reduce agricultural GHG emissions by 2020 were limited to just over 1 Mt CO_2eq using the IPCC inventory approach, or 2.5 Mt CO_2eq using a lifecycle assessment approach. In practice, and in context of the projected growth of the agricultural industry under a Food Harvest 2020 scenario, this meant that this 'old' approach would at best allow agricultural GHG emissions to be maintained at current levels while growing agricultural outputs. This would imply a degree of decoupling of agricultural activity and GHG emissions that would be a significant achievement in its own right.

The concept of carbon-neutrality allows the agricultural sector to widen its horizons and to consider offsetting mechanisms such as carbon sequestration and fossil fuel displacement into its menu of options to reduce the impact of agriculture and land use on global GHG emissions. Our current report shows that this allows a significant expansion in the potential and positive contribution that agriculture can make. It shows that it is not only possible to decouple GHG emissions from agricultural activity, in fact the concept of carbon-neutrality allows agriculture to make real and proactive reductions to the agricultural, and hence national 'emissions gap'.

Put differently, in the context of our Pathway assessment: under the previous approach ('reducing agricultural emissions') agriculture could only resort to two pathways, i.e. Pathways B and D. Under the new approach ('carbon neutrality'), Pathways A and C can be added to the mix, which are two pathways with significant potential (Table 5.1). It also allows Pathway E to be considered in the context of finding global solutions to the twin challenges of food security and combating climate change.

This leads to our last conclusion:

<u>Conclusion 5: Carbon-neutrality for agriculture as a concept and a horizon point for 2050 radically diversifies the menu of options for agriculture to make a meaningful and proactive contribution to reducing national GHG emissions.</u>

5.2.2 Unresolved aspects of the carbon-neutrality concept

At the same time, in our assessment we have come across a number of aspects of carbon-neutrality as a concept that need further clarification or exploration.

System boundaries

As discussed in Section 2.1.3, we limited the quantitative aspects of our assessment to *national* emissions of GHGs, and qualitatively discussed the potential effects of embedded emissions and potential for carbon-leakage on global GHG emissions in the section on 'contextual considerations' for each pathway.

In our previous MACC report, which focussed solely on measures aimed at reducing emissions, we conducted and contrasted two analyses for two different system boundaries:

1. National boundaries, using the IPCC inventory methodology, which accounts only for emissions that occur within country boundaries;
2. Lifecycle boundaries, using Lifecycle Assessment (LCA) methodologies, which additionally accounts for 'embedded emissions', i.e. emissions associated with the production of imported agricultural inputs (e.g. fertilizer, animal feed products).

We concluded that the LCA methodologies were preferable, in that they take account of the true impact of agricultural production at a global (rather than national) scale, and thus reduce the potential risks of perverse measures to be incentivised, or of carbon leakage.

In an ideal scenario, therefore, the concept of carbon-neutrality would be combined with an LCA approach. However, this will be an extremely complicated and onerous task, since such an assessment would need to take account of not only differences in carbon-efficiency of agricultural production systems around the world, but also of differences in the offsetting efficiencies of different regions around the world, which in turn depends on existing land use and soil characteristic.

Accounting across sectors

Secondly, to some extent our pathway assessment crosses over into other sectors of society. Specifically Pathway C crosses over with the power generation sector. As discussed in Section 5.4, this carries a risk of 'double-counting'. The power generation sector has been set a goal of 100% renewables by 2050. If this goal is achieved partially through energy generation from biomass, then it is yet unclear whether the contribution from bioenergy production can or should be counted as a success for both sectors.

At the same time, energy generation from biomass can make a positive contribution to reducing the overall national GHG emissions. Experience has taught us that debates on which sector should be credited with carbon-credits can distract the attention from efforts to incentivise cross-sectoral offsetting mechanisms.

Finally, it is worth noting that internationally too, cross-sectoral offsetting features as a pathway towards carbon-neutral agriculture. For example, the approach adopted by the

Farmers & Climate project in the Netherlands accounts not only carbon sequestered in biomass crops, in addition it includes on-farm energy generation through wind and solar power (Wijnands *et al.*, 2013; see www.farmersandclimate.nl for details).

5.3 Concluding remarks

In this report, we assessed the concept of carbon neutrality as a conceptual framework for the development of a roadmap that allows agriculture to make a meaningful and proactive contribution to reducing national and global GHG emissions, while at the same time contributing to global food security and the rural economy in Ireland.

Our assessment is highly dependent on external factors and as such surrounded by significant uncertainties; for this reason, we limited our analysis largely to a qualitative appraisal of contrasting pathways towards carbon-neutrality.

We find ourselves at an unusual juxtaposition between international and national drivers. On the one hand, many of our projections and assessments depend primarily on global developments in the period to 2050, specifically population growth, changes in dietary preferences in emerging, but also developed economies, changes in land use and the potential impacts of climate change itself. At this point it is impossible to quantitatively predict these drivers with any degree of accuracy. Similarly, in the early 1970s it would have been impossible to predict the magnitude of the climate change challenge, as compared to e.g. the challenges of ‘acid rain’ and the ‘ozone layer’, which dominated the environmental debate throughout the 1980s and into the 1990s.

Therefore, the outcomes of the global debates on food security and climate change will depend primarily on global patterns of food production, distribution and consumption. Referring back to the JRC scenarios (Section 2.3.2), changes in demand for food will have profound impacts on the achievability of carbon-neutral agriculture in Ireland. For example, a ‘sustainable but short’ scenario, as mediated by changes in consumption and restrictive (international) policies, would reduce growth opportunities for Irish agriculture which would make carbon neutrality less onerous to achieve, but at the expense of higher food prices and inequitable access to food. Contrastingly, a BAU scenario, in which international efforts to reduce GHG emissions fail, may complicate unilateral efforts in Ireland to progress towards carbon-neutrality.

At the same time, whilst many of the external drivers for sustainable food production operate at an international scale, the successful incentivisation of the five pathways assessed in this report, depends on national policy initiatives, such as afforestation programmes, investment in research and KT, as well as creating an enabling environment for bioenergy production. Some of the measures needed do not yet sit easy within the context of international negotiations on a post-Kyoto climate agreement. However, given the slow pace of progress of these negotiations, and given the fact that progress in these negotiations may well rely on ‘success stories’ of countries that experimented with new approaches, it would be unwise not to heed the tagline of the report from the NESC secretariat, i.e. “thinking for ourselves”, bearing in mind the cost-benefit ratios associated with each of these pathways.

The crux here is that carbon-neutrality, even as a horizon point, is an ambitious target that cannot be achieved over any short time period. Put simply, we will need every single year in the period to 2050 in order to make significant progress in reducing the emissions gap from agriculture. For that reason, we do not have the luxury of ‘waiting and assessing’ the direction of the external international drivers, before deciding on the preferred plan of implementation. To some extent, implementation of Pathway F (‘mosaic of solutions’) therefore represents a leap of faith that, by 2050, carbon neutrality will prove to have been the correct approach to addressing the global challenges for 2050, as perceived as far back as today.

In this report we have provided a range of options, and highlighted their potential, constraints, and their contextual ‘pros and cons’. We highlighted that there is no easy option or silver bullet to reduce agricultural emissions, and at the same time, that there is significant potential to reduce the ‘emissions gap’ through a combination of pathways. Decisions on the pathway of choice, or the scale of the ambition, are not decisions for Teagasc; these are decisions for society as a whole.

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