Irish Agriculture, Greenhouse Gas Emissions and Climate Change:

opportunities, obstacles and proposed solutions

Prepared by the

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EXECUTIVE SUMMARY

1. Agriculture contributes to global balances of greenhouse gases (GHGs) through emissions of nitrous oxide and methane and through emissions and/or sequestration of carbon dioxide. In Ireland, GHG emissions from agriculture represent 29.1% of total national GHG emissions. The emission reduction target of 30% by 2020, specified in the Climate Change Response Bill, applies to national emissions. In a hypothetical scenario of proportional burden sharing across sectors, where this overall target translates into a 30% reduction target for the agricultural sector, this will have significant implications for the sustainable development of this important indigenous industry. This submission highlights key international and national issues that must be considered in preparing any GHG control instruments with a specific focus on agriculture.

2. Achieving the apparently contradictory and intertwined objectives of combating climate change and achieving food security is accepted to be one of the most important policy challenges for the world at the start of the 21st century. Global demand for food is forecast to rise substantially over the first half of this century, and it has been projected that this will result in a 24% increase in global GHG emissions from agriculture over the period 2005-2020. Therefore, the most pertinent global policy challenge in this regard is to minimise this *increase* in GHG emissions, and this has consequences for the approach required to reducing GHG emissions at national level.

3. Policies and efforts to incentivise abatement of GHG emissions should ensure that efforts to reduce *national* GHG emissions from agriculture do not lead to an inadvertent *increase* in *global* GHG emissions through carbon leakage. The impact of rising food demand means, other things being equal, that a reduction in food production in Ireland to meet national GHG reduction targets would result in increased food production elsewhere. This can result in a net increase in global GHG emissions, if the countries expanding food production were unable to produce food with an emissions intensity that is as low as in Ireland. This is particularly likely where deforestation or removal of native ecosystems would take place to allow increased agricultural production. It is estimated that, if the sectoral plan for agriculture were to lead to a hypothetical 50% reduction in Irish beef production, displacement of this to South America could lead to an additional net *c*. 3.6 Mt *increase* in global GHG emissions. An impact of this nature is referred to as carbon leakage.

4. The choice of metric in quantifying and reporting GHG emissions from agriculture is pivotal in preventing carbon leakage, and to ensure that only those mitigation strategies and farming systems that do not exacerbate carbon leakage are incentivised. In this context, 'emission intensity', or GHG emissions per unit of product, rather than 'absolute emissions' (which effectively equate to GHG emissions per hectare), should be used as the metric of choice. This metric could readily be used for the purpose of internal national offsetting, but adoption of this at international level will require significant policy efforts.

5. The emission reduction target of 30% by 2020, specified in the Climate Change Response Bill, applies to national emissions. In a hypothetical scenario of proportional burden sharing across sectors, where this overall target translates into a 30% reduction target for the agricultural sector, this is expected to result in a very significant reduction in the national beef herd (assuming all the reductions were concentrated in that sector). The number of suckler cows would reduce to 190,000 from a current herd of 1.15 million. This would reduce the value of beef output by €729 million per annum, and reduce the value of beef processing industry by €1,136 million per annum. The reduction in gross value added in the agri-food sector associated with the achievement of the 30% GHG reduction target is projected to be €371 million per annum by 2020. Considering the importance of the beef industry and beef processing industry to the rural economy, this reduction would have far-reaching consequences for rural communities

6. Agriculture is the primary non-ETS sector that has reduced GHG emissions since 1990: in 2009, the rate of agricultural emissions was 9.1% below the rate in 1990 and 17.1% lower than in 1998. In a Business As Usual scenario, GHG emissions from agriculture are expected to see a further reduction of 5% by 2020, compared to 2008. However, agricultural emissions are expected to increase by 3% in an alternative scenario that accounts for the production targets for the sector set by the Department of Agriculture, Fisheries and Food (DAFF) in the recent Food Harvest 2020 report. This, and the relatively small potential of current mitigation measures in the sector (as discussed in this submission), show the difficulty for the agri-food sector to achieve significant further absolute reductions on current emissions.

7. Teagasc, in collaboration with Higher Educational Institutes in Ireland and abroad, and co-funded by DAFF, EPA, SFI and EU Framework 7 and INTERREG IV, is conducting research on a suite of mitigation options aimed at reducing the emission *intensity*, or carbon-footprint, of Irish produce. Options include: improvement of the genetic merit of cows, extension of the grazing season, reducing beef finishing times, restructuring of the national bovine herd, improvement of N-efficiency, increased use of clover, dietary modification, use of nitrification inhibitors and minimum tillage techniques. These mitigation options differ in their potential impact and cost-efficacy. Options based on improvements in resource utilisation (e.g. nutrients, genetic merit) are expected to be cost-beneficial, whereas other options may be associated with increased costs. Overall, Teagasc estimates that implementation of suites of mitigation options have the *technical* potential to reduce the emission intensity, i.e. the GHG emissions *per kg product*, of both dairy and beef produce by 15-20% by 2020.

8. Forestry provides a significant potential opportunity to offset GHG emissions from the agricultural sector through carbon sequestration. Similarly, the domestic production and use of biofuel and bioenergy has potential to offset GHG emissions by displacement of fossil fuels.

9. Maximisation of the adoption of these mitigation and offsetting options will require further financial incentivisation; this can take the form of market-driven incentivisation, or through implementation of a domestic offsetting scheme. These two pathways for incentivisation are not necessarily mutually exclusive. However, there are significant institutional obstacles to both the inclusion of these options into national inventories and further incentivisation of mitigation and offsetting opportunities for agriculture. These include 1) the complexities involved in the verification of farm-based GHG emissions, which is required for implementation of incentivisation strategies; 2) the allocation of carbon offsetting by forestry to the LULUCF sector and 3) the allocation of carbon offsetting by biofuel and bioenergy production to non-agricultural sectors.

10. Implementation of a domestic offsetting scheme has potential to (partially) overcome these obstacles. However, for such a scheme to be effective, it is crucial that due consideration is given to 1) the choice of metric; 2) the point of obligation; 3) associated carbon-accountancy requirements and 4) the need to avoid "pollution swapping". Teagasc proposes that the effectiveness and equitability of a domestic offsetting scheme can be strengthened by 1) a phased role-out of such a scheme through the sector; 2) the use of partial, as opposed to full life cycle analyses and 3) careful selection of mitigation and/or offsetting measures, taking account of the cost-effectiveness of each of the measures.

11. Climate change has been predicted to have significant impacts on agricultural productivity at global level. In Ireland, the predicted impacts are less severe, and may be beneficial to agriculture in some cases. More substantial impacts of climate change are predicted for forestry in Ireland, with increased prevalence of pest and diseases, and potential losses in forest productivity.

12. Finally, strategies to reduce GHG emissions from agriculture should not only take account of the requirement to simultaneously meet the challenge of achieving food security; in addition, these should be considered in the wider context of the sustainability functions provided by agriculture, which includes provision of clean water and habitats for biodiversity. A spatially explicit approach may be required to ensure maximisation of all sustainability functions.

GLOSSARY

AD	Anaerobic Digestion
BAU	Business As Usual
C	Carbon
CH_4	Methane
CMMS	Cattle Movement Monitoring System
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
COFORD	Programme of Competitive Forest Research for Development
CSO	Central Statistics Office
DAFF	Department of Agriculture, Fisheries and Food
DCD	Dicyandiamide
DO	Domestic Offsetting
DOEHLG	Department of Environment, Heritage and Local Government
EBI	Economic Breeding Index
EPA	Environmental Protection Agency (Ireland)
ETS	Emissions Trading Scheme
EU	European Union
FAO	Food and Agriculture Organisation
FAPRI	Food and Agricultural Policy Research Institute
FH	Food Harvest 2020 (in scenario analyses)
FHEQ	Food Harvest 2020 with emissions quota (in scenario analyses)
FPCM	Fat and Protein Corrected Milk
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
LU	Livestock Unit
LULUCF	Land Use, Land Use Change and Forestry
Mt	Megaton
N	Nitrogen
N_2	Di-nitrogen gas
N_2O	Nitrous Oxide
NFS	National Farm Survey

NZ MoE	New Zealand Ministry of Environment
OECD	Organisation for Economic Cooperation and Development
PPR	Pasture, Paddock and Range
REPS	Rural Environment Protection Scheme
SEAI	Sustainable Energy Authority of Ireland
SFI	Science Foundation Ireland
SOC	Soil Organic Carbon
TMR	Total Mixed Ration
UCD	University College Dublin
UNFCCC	United Nations Framework Convention on Climate Change
US-EPA	United States Environmental Protection Agency

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1. INTRODUCTION

Teagasc welcomes the opportunity to make a formal submission to the public consultation on the proposed Climate Change Response Bill, published by the Department of Environment, Heritage and Local Government in December 2010.

Teagasc acknowledges the threats posed by climate change resulting from anthropogenic emissions of greenhouse gas (GHG) emissions, and recognises that concerted and urgent action is required to reduce or negate the future impacts of these threats.

Since GHG emissions and climate change both operate at a global, rather than at national or regional scale, it is self-evident that, in this respect, collaborative efforts are required to ensure that actions to combat climate change are meaningful, significant, and moreover, that equitable responsibilities are assumed by all jurisdictions. In addition, at national level, actions to reduce climate change and GHG emissions are the collective responsibility of all sectors of society. A coordinated, coherent and equitable cross-sectoral strategy to abating GHG emissions in Ireland is required, including GHG emissions from the agricultural sector. In this respect, Teagasc welcomes the opportunity, provided by the consultation process for the Climate Change Response Bill, to contribute to the discussions and development of such a strategy.

This submission demonstrates that, in the case of the agricultural sector, selection of the correct approach to abatement of GHG emissions is critical. There is considerable potential for the agricultural sector in Ireland to contribute to abatement of GHG emissions, and that concerted action by all stakeholders in the Irish agri-food industry may indeed generate opportunities that are consistent with both climate change objectives and the economic objectives set out in the recent Food Harvest 2020 report (DAFF, 2010). However, the potential to capitalise on these opportunities will depend to a large extent on the details of the sectoral policy plan for reducing GHG emissions from the agricultural sector, to be developed as part of the implementation of the Climate Change Response Bill.

The body of scientific evidence in this submission demonstrates that the abatement of GHG emissions from agriculture is extremely complex and cross-sectoral, and that it is imperative that efforts to incentivise abatement strategies fully recognise this complexity. Failure to recognise this complexity could potentially result in strategies that are not only in conflict with the targets and objectives for the agricultural industry, outlined in the Food Harvest 2020 report, but that may inadvertently lead to increased global GHG emissions.

In this submission, Teagasc is pleased to avail of the opportunity to share its considerable knowledge and expertise on strategies for the abatement of GHG emissions from the agricultural sector. Over the last ten years, Teagasc has developed substantial critical mass in research on GHG from agriculture, and currently invests in excess of €3million per annum on its GHG research programme, co-funded by DAFF, EPA, SFI and the EU Framework 7 and INTERREG IV Programmes. In this research programme, Teagasc proactively collaborates with universities in Ireland and abroad. In addition, it is a proactive member of the Global Research Alliance (www.globalresearchalliance.org), and the EU Joint Programme Initiative on "Agriculture, Food Security and Climate Change" (www.faccejpi.com) and is a workpackage leader of a CSA that will further develop this initiative.

This submission coherently collates the collective expertise in Teagasc in relation to agriculture and climate change, and encompasses elements of soil science, crop science, animal science and economics, as well as the "real world" experience of farm advisors and specialists. This submission was prepared by Teagasc's Working Group on Greenhouse Gas Emissions, which coordinates and integrates all of Teagasc's activities in relation to GHG emissions and climate change.

Section 2 of this document summarises the composition, trends, and projections of agricultural GHG emissions, and investigates the potential impacts of the hypothetical imposition of a fixed carbon quota on the sector. Section 3 discusses strategies required for the abatement of agricultural GHG emissions at global level. Section 4 outlines agricultural strategies that, at national level, can contribute to meeting these global objectives. Section 5 identifies obstacles to implementing and incentivising these strategies at national level, while Section 6 briefly discusses the potential impacts of climate change on agriculture and forestry.

Through its research, advisory and technology transfer activities, Teagasc is committed to generating and contributing the knowledge, data and expertise that is required to the ongoing development and implementation of strategies that reduce the "carbon footprint" of Irish agricultural produce.

2. Irish Agriculture and GHG emissions: composition, trends and projections

2.1 Composition of agricultural Greenhouse Gas Emissions

2.1.1 Proportional emissions from agriculture

Ireland is unique among the EU countries for the proportion of its greenhouse gas (GHG) emissions which originate from agriculture, representing 29.1% of national and 40% of the non-Emissions Traded Sector (non-ETS) emissions. This proportion is high compared to the EU average of 9%, and reflects the relative importance of agriculture, which is predominantly based on export of ruminant livestock products, to the Irish economy (Breen *et al.*, 2010). Amongst the developed economies, only New Zealand has a higher proportion of national GHG emissions associated with agriculture (NZ-MoE, 2010).

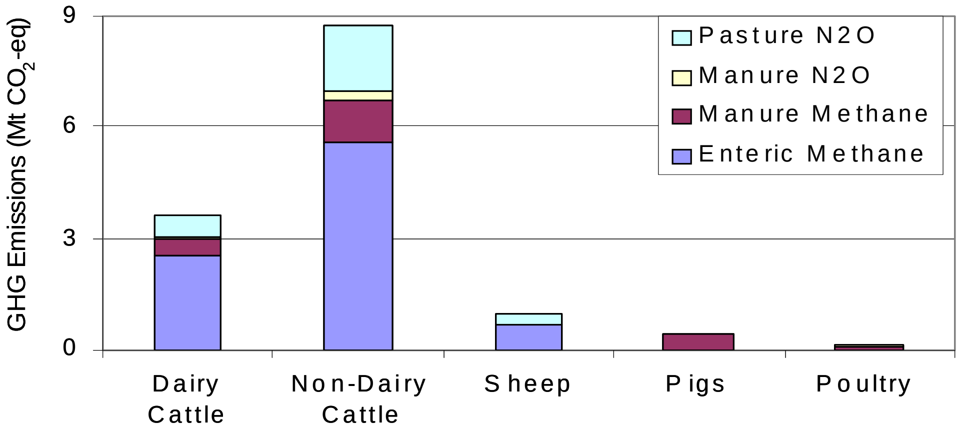


Figure 1: Sources of greenhouse gas emissions arising from livestock production in 2008 (McGettingan et al., 2010b).

2.1.2 Sources of agricultural emissions

The latest reported (2008) emissions from the Irish agricultural sector amount to 18.1 Mt carbon-dioxide equivalents (CO_2eq). These emissions are dominated by methane (CH_4) and nitrous oxide (N_2O) (McGettigan *et al.*, 2010a). This emissions profile arises because of the dominance of cattle and sheep livestock production in Irish agricultural output (Figure 1). Methane emissions sourced from livestock enteric fermentation is the primary source of greenhouse gases, accounting for almost 50% of total emissions. The two other major sources are methane emissions from manure management (14.5%) and N_2O emissions arising as a result of chemical/organic fertilizer application and animal deposition (35.6%).

2.2 Historic trends of agricultural Greenhouse Gas Emissions

National cross-sectoral greenhouse gas (GHG) emissions increased in line with economic growth; during the ten years leading up to 2009, mean annual emissions were 67.8 Mt of CO_2eq, or 23.8% above 1990 levels (McGettigan *et al*., 2010b). However, in 2009, emissions decreased by 5.36 Mt CO_2eq to 14.1% above the reference year, reflecting the 8.5 % contraction in Gross Domestic Product. Both the prior increase in emissions up to 2009, and subsequent decrease was principally driven by fluctuations in industrial, power generation and transport emissions. Despite the downturn, by 2009 emissions associated with both transport and power generation had risen by 156% and 15%, respectively, relative to the reference year of 1990 (McGettigan *et al*., 2010a). By contrast, agricultural emissions have been in steady decline since 1998, with total sectoral emissions 9.1% lower than the reference levels and 17.1% lower than the 1998 maximum (McGettigan *et al*., 2010a).

2.2.1 Methane trends

The reduction in total methane emissions has been driven primarily by decreases in the total number of beef cattle and sheep. However, whilst sheep emissions have decreased linearly with ovine meat production (30%), there has been a decoupling between cattle emissions and total production (Figure 2). Methane emissions for beef cattle fell by 10% between 1998 and 2006, whilst beef production fell by 3% (Figure 2b). Similarly, dairy-sourced methane emissions fell by 13% between 1990 and 2006, associated with a reduced milk output of 3%. This decoupling was mainly driven by improved efficiency of production, specifically reduced finishing times in the beef sector and increased milk production per head in the dairy sector. An important caveat in this observation is that further improvements in production efficiency will be incrementally more challenging to obtain, which will be elaborated on in Section 4 of this submission. As a result, this historic decoupling of livestock numbers and GHG emissions cannot and should not be symmetrically projected into future scenarios.

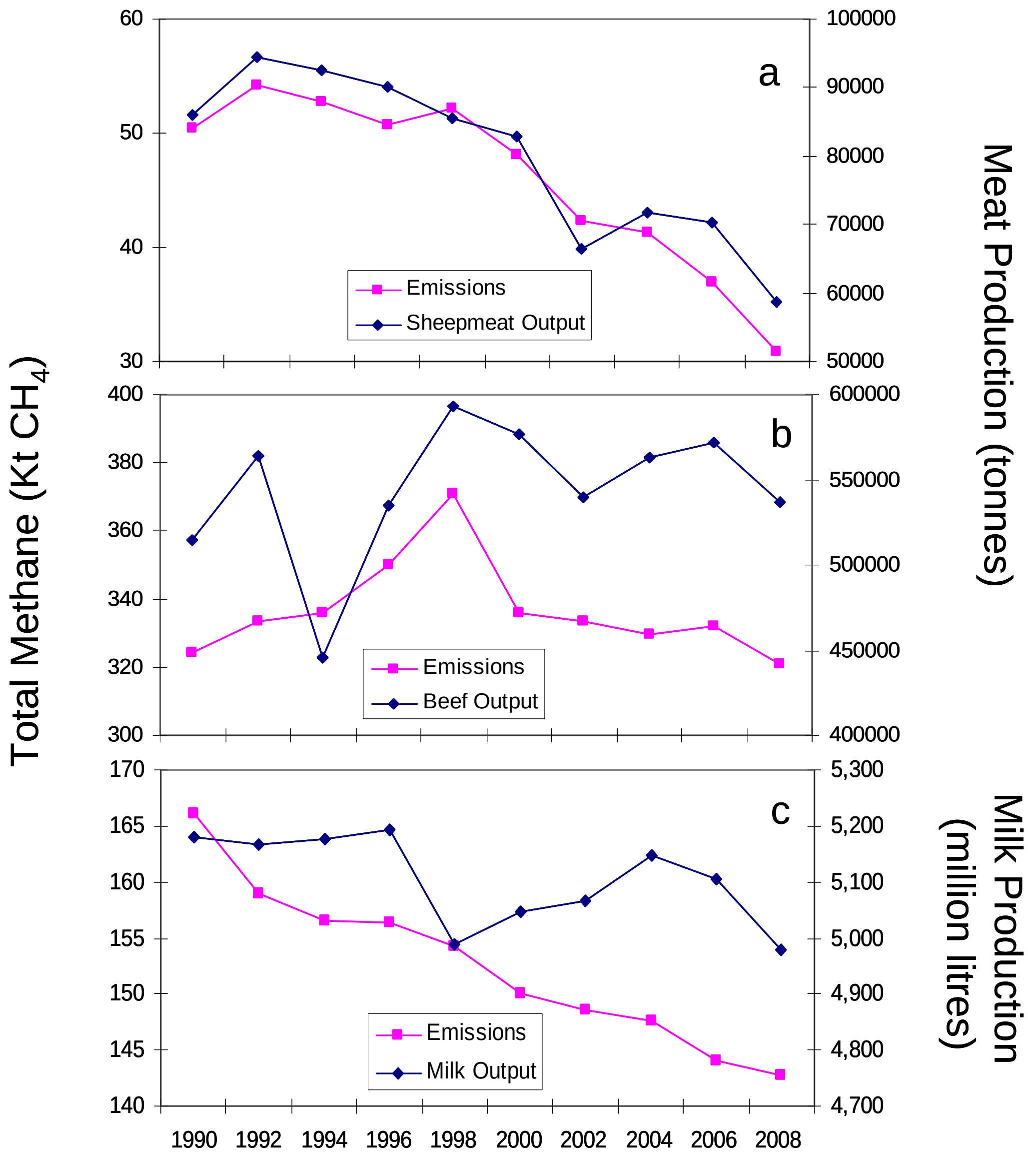


Figure 2: Total methane emissions (associated with both enteric fermentation and manure management) and agricultural production for a) sheep, b) beef and c) dairy cattle between 1990 and 2008.

2.2.2 Nitrous oxide trends

Nitrous oxide emissions arise as a result of the deposition of urine and faecal nitrogen (N) from livestock, the application of chemical and organic nitrogen fertilizers and, indirectly, from ammonia volatilisation and leached N (Flechard *et al.*, 2007). Total agricultural N_2O emissions have decreased by 11% relative to 1990 and over 20% relative to 1998 peak emissions (McGettigan *et al.*, 2010b). Decreased N_2O emissions arising from animal deposition, termed pasture, paddock and range (PPR) emissions, have followed a similar trend to methane emissions, with the principal reductions arising from sheep (38%) and non-dairy cattle (11%) (Figure 3a). Similarly, reductions in the application of mineral fertiliser resulted in a 28.9% decrease in associated emissions between 1998 and 2008, associated with a 30% increase in fertiliser costs since 2000 (Lalor *et al.*, 2010). Whilst inputs of mineral N have decreased, the use of organic fertiliser (and associated emissions) has remained constant despite decreases in the total livestock numbers.

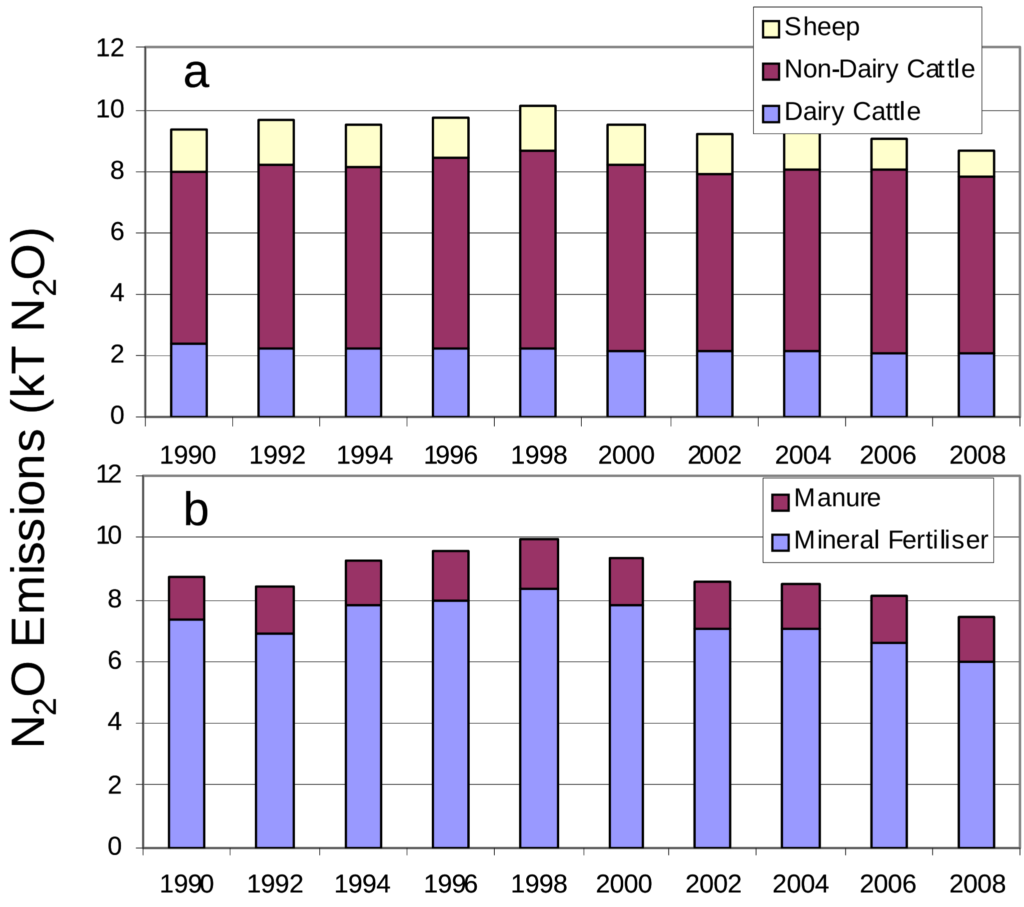


Figure 3: Nitrous oxide (N2O) emissions sourced from a) pasture, paddock and range emissions and b) mineral and organic fertiliser usage between 1990 and 2008. Source: McGettingan et al. (2010b).

In addition, indirect emissions due to ammonia volatilisation decreased by 18%. This reflected an increased efficiency in the use of organic fertilisers, primarily due to land-spreading earlier in the year during periods when ammonia release is low (Dowling *et al.*, 2009; Meade *et al.*, 2011).

2.3 Future projections of agricultural Greenhouse Gas Emissions: scenario analysis

A variety of projections have been published on future trends of agricultural GHG emissions. The quantitative outcomes of each of these projections depend on underlying model assumptions and choice of reference year. For this submission, Teagasc has analysed two scenarios of future trends:

1. "Business As Usual" (BAU) scenario, published by the Environmental Protection Agency (EPA)
2. Food Harvest 2020 (FH) scenario, which incorporates the effects of achieving the growth targets for the agricultural industry, set in the Food Harvest 2020 report.

In addition, Teagasc has analysed the impact of the hypothetical imposition of a carbon quota, or target reduction in absolute emissions, on the economic value of the Irish agri-food industry. This will be referred to as the Food Harvest 2020 plus Emission Quota (FHEQ) scenarios.

2.3.1 Business as Usual scenario

The EPA has published emissions projections for all relevant sectors up to 2020 (EPA, 2010). These projections were based on two scenarios. The first ("With Measures"), here referred to as BAU1, consisted of a baseline energy forecast and incorporated the effects of policies already in place. It assumed an average yearly gap of 3 Mt CO_2eq between national and Kyoto target emissions for the reporting period (2008-12). The second scenario ("With Additional Measures") *additionally* incorporated the impacts of the Energy White Paper and set a lower distance form target of 2.5 Mt CO_2eq a^{-1} (EPA, 2010). The mean distance from target for the years 2008-2009 so far has been 3.1 Mt CO_2eq a^{-1} indicating that the first scenario currently is the most appropriate (McGettigan *et al*., 2010a).

Emissions projections for enteric fermentation, manure management and N_2O from soils were based on projections of animal numbers, crop areas and nitrogen fertiliser rates, taking into account increases in the national milk quota prior to quota removal in 2015. The impacts of Food Harvest 2020 production targets or the efficacy of agricultural mitigation were *not* incorporated.

Under the BAU1 scenario, total emissions from agriculture were forecast to decrease by 5% over the period 2008 – 2020 to 17.5 MT CO_2eq. Under the BAU1 scenario, agricultural emissions as a proportion of total non-ETS emissions were projected to decrease from the current 40% to 35%, whilst under the BAU2 scenario, the proportion would be 39%.

2.3.2 Food Harvest 2020 scenario

Food Harvest 2020 has proposed ambitious targets in terms of Irish Agricultural production by 2020. The dairy output target is an increase of 50% in milk production by 2020 relative to the average volume of production over the period 2007-2009. No volume target is set for beef or sheep production, rather a target of increasing the output value from each of these sectors by 20% by 2020 is set relative to the average of the period 2007-2009. In the case of the pig sector the target is to increase output value by 50% by 2020. Targets for forestry and bioenergy crops are not specified, but for the purposes of this analysis an annual growth target of 7,500 ha per year is used for forestry and for bioenergy crops a target of 4,000 ha per year is specified.

The FAPRI-Ireland model (Donnellan & Hanrahan, 2006; Binfield *et al.*, 2009) has been used extensively in the analysis of agricultural and trade policy changes in Ireland over the last 10 years. Here, the FAPRI-Ireland model was used to estimate the agricultural income (operating surplus) figure associated with achievement of the Food Harvest 2020 targets. It is found that this would lead to an increase in agricultural income of just over € 1,000 million, representing an increase of 48% relative to the average for the period 2007-2009 (Figure 4). This mainly reflects the increase in the value of milk output (and milk prices due to the production of higher value added dairy products) necessary to provide the 50% volume increase in milk production, but it also reflects the fact that beef production with a low level of profitability is being replaced by milk production with a higher level of profitability.

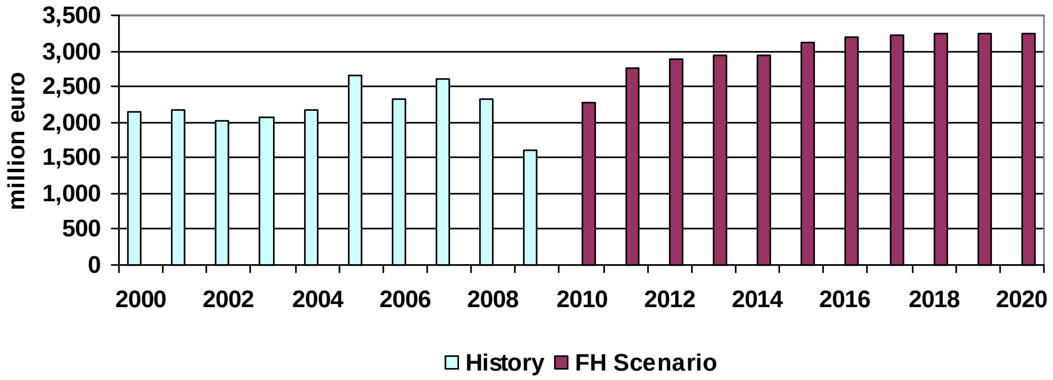


Figure 4: Irish Agricultural Sector Income: Historical and Food Harvest 2020 Projections.

The FAPRI-Ireland model was also used to project the Food Harvest 2020 level of agricultural production, to determine the associated level of input usage, and to project GHG emissions from Irish agriculture associated with the FH scenario for the period 2005 to 2020 (Figure 5). Emissions associated with fuel combustion were not included in the analysis.

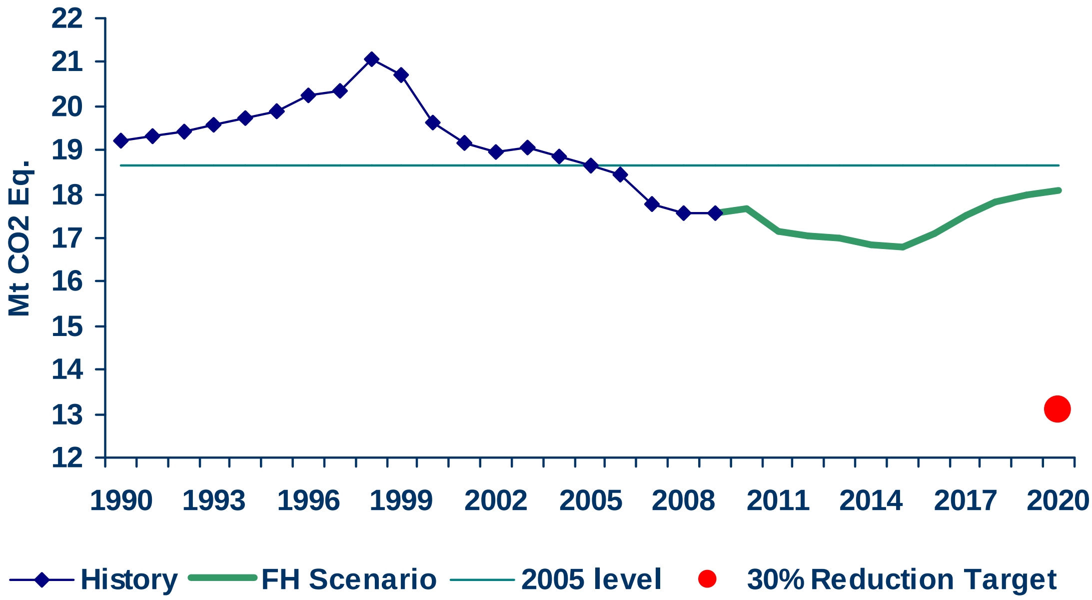


Figure 5: Historical and projected GHG emissions from Irish Agriculture under the FH scenario.
Note: Excludes emissions from fuel combustion.

Under the FH scenario, GHG emissions are projected to increase in the coming years, principally as a result of the increase in dairy cow numbers and associated dairy emissions, which are predicted to more than offset the contraction in emissions following a reduction in the size of the suckler herd. By 2020, the level of GHG emissions under this scenario are projected to be 18.06 Mt CO_2 eq, representing a *decrease* of *c.* 3% compared to 2005, or an *increase* of *c.* 3% compared to 2009.

2.3.3 Impact of imposing hypothetical fixed GHG targets on agricultural GHG emissions

Whilst the proposed Climate Change Response Bill proposes aggregate reduction targets for 2020, 2030 and 2050 for national GHG emissions, it does not specify how these reduction targets will be translated into targets for individual sectors within the non-ETS sector.

To assess the impact of the imposition of hypothetical GHG reduction targets onto the agricultural sector, Teagasc analysed the effects of hypothetical reduction targets of 10%, 20% and 30% on the economic value of the agri-food industry, compared to the FH scenario (section 2.3.2 above); and these will be referred to as the FHEQ10, FHEQ20 and FHEQ30 scenarios. The reductions targets would equate to absolute reductions by 2020 of 1.87, 3.73 and 5.60 Mt CO_2eq, respectively, relative to the 2005 reference year.

For the purposes of this analysis, it was assumed that the reduction in emissions that are needed to meet the reduction targets will take place gradually over a ten year period from 2011 to 2020. It was assumed in this analysis that the reductions in emissions required to achieve the three reduction target (10, 20 and 30%) are achieved through reductions in the number of beef cattle (i.e. suckler cows, and their progeny), since the gross margin *per tonne* of CO_2eq emissions of Irish beef enterprises are less than a quarter of the corresponding gross margin for dairy enterprises (Breen *et al.*, 2010). Therefore, this analysis represents a hypothetical scenario, where GHG reduction targets would be merely achieved through the imposition of a crude quota on animal numbers. There is a need to examine alternative, more realistic scenarios that would achieve similar GHG reductions. Using the FAPRI-Ireland model it is possible to evaluate such other options.

As beef cattle numbers decline to achieve the 30 percent reduction target, land would become available for other agricultural purposes (or else production would become extremely extensive). It is important to note that the impact on GHG emissions of the conversion of land previously used for beef cattle, to use for bio-energy crop production, dairy, tillage, forestry, land abandonment etc. would have varying implications for both GHG emission levels emissions and wider environmental criteria (e.g. water quality, biodiversity). Detailed consideration of the impact of these different alternative uses of surplus land has not been made in this analysis.

In the FHEQ10, FHEQ20 and FHEQ30 scenarios, the GHG reduction targets of 10%, 20% and 30% require that total cattle numbers are reduced to 5.22 million, 4.48 million and 3.70 million head by 2020, respectively, down from 6.21 million head in 2005 and 5.72 million in 2020 under the FH scenario. Suckler cows numbers are reduced to just over 0.74 million, 0.49 million and 0.27 million head, respectively, by 2020, down from 1.15 million head in 2005 and 0.93 million in 2020 under the FH scenario. Accordingly, by 2020 Irish beef production would decrease to 0.52, 0.43 and 0.33 Mt to achieve reduction targets of 10%, 20% and 30%, respectively, down from 0.55 Mt in 2005 and 0.57 Mt in 2020 under the FH scenario.

Beef prices in 2020 are projected to be higher than in 2005. Rising beef prices wiil partially offset the impact of the reduction in the quantity of beef produced, in both the FH and the FHEQ reduction scenario in 2020. This means that the percent decline in beef output value is smaller than the percentage quantity reduction in both cases. By 2020 the value of the cattle sector in the three FHEQ10, FHEQ20 and FHEQ30 scenarios is €1,705, €1,437 and €1,171 million, respectively, down from just over €1,400 million in 2005 and € 1,900 million in the FH scenario (Table 1). Given that little change in Irish beef consumption is projected over the period to 2020, the impact of meeting the reduction targets on the value of beef production would be mirrored by a broadly similar percentage reduction in the value of Irish beef exports.

The output value of beef processing in 2020 under the FH scenario is estimated to be about € 2,960 million. The cattle used to produce this beef are sourced almost exclusively in Ireland. If beef production were to decline in response to GHG reduction targets of 10%, 20% or 30%, then the value of output in beef processing would decline by €304 million, €721 million and €1,136 million to about €2,656 m, €2,239 million and €1,824 million, respectively.

The change in economic value associated with changes in agricultural and beef processing industry output are not equivalent due to changes in the costs of production that would be associated with the reduced levels of beef output under FHEQ10, FHEQ20 and FHEQ30. Table 1 provides information on the change in agricultural sector income under the FHEQ10, FHEQ20 and FHEQ30 scenarios. Table 2 provides equivalent information on the estimated change in gross value added in the beef processing industry under the FHEQ10, FHEQ20 and FHEQ30 scenarios.

The change in economic value associated with changes in agricultural and beef processing industry output are not equivalent due to changes in the costs of production that would be associated with the reduced levels of beef output under FHEQ10, FHEQ20 and FHEQ30. Table 1 provides information on the change in agricultural sector income under the FHEQ10, FHEQ20 and FHEQ30 scenarios. Table 2 provides equivalent information on the estimated change in gross value added in the beef processing industry under the FHEQ10, FHEQ20 and FHEQ30 scenarios.

Table 1: Historical and projected Sectoral Income under Food Harvest 2020 and under the 10, 20 and 30 percent GHG reduction target**.**

	2007-2009 average	**2020**	**Increase on 2007-2009 average**	**% change**
	Million Euro			
FH Scenario		3,233	1,051	48
FHEQ10		3,184	1,002	46
Change vs FH		-49		
FHEQ20	**2,182**	3,117	935	43
Change vs FH		-116		
FHEQ30		3,038	856	39
Change vs FH		-195		

Table 2: Impact of GHG reduction on the Output and Value added in Beef Processing. Source: FAPRI-Ireland (2011)

	2005	**FH**	**FHEQ10**	**FHEQ20**	**FHEQ30**
Output (€ m)	2,200	2,960	2,656	2,239	1,824
Change relative to FH (€ m)			-304	-721	-1,136
GVA (€ m)	286	460	413	348	284
change relative to FH (€ m)			-47	-112	-176
% reduction in GVA relative to FH			-10	-16	-19

The summation of changes in output value at the farm and food processing industry levels is invalid since it would involve a double counting of output value since the agriculture sector's output is an input to the food processing industry. It is however valid to sum the level and changes in the level of value added in the agricultural sector (operating surplus) and gross value added in the beef processing industry. It is this sum that represents the change in the economic value that can be attributed to the imposition of the 10, 20 and 30 percent GHG reduction targets on primary agriculture.

3. Abatement strategies for global agricultural GHG emissions.

3.1 Global agricultural GHG emissions and Food Security are intertwined

Recent estimates put the global GHG emissions from the agriculture sector at 10-12% of global GHG emissions (Denman *et al.*, 2007 and US-EPA, 2006, respectively), with 75% arising from non-Annex 1 countries, principally South and East Asia and Latin America (Smith *et al.*, 2007). FAO projections suggest that increases in global population and wealth will increase demand for food by more than 50% by 2030, and 100% by 2050 (Bruinsma, 2009; Huang *et al*., 2010). For livestock produce, projections show even sharper increases in global demand. Meat demand in many countries, notably China, doubled during the period 1967–1997. Rosegrant *et al*. (2001) forecast a 57% increase in global meat demand between 2000 and 2020, mostly in regions at lower latitudes such as South and Southeast Asia and Sub-Saharan Africa. In 2006, the FAO (2006) predicted that the increase in demand for both meat and dairy products will slow after 2030. More recent assessments forecast a 110% and 80% increase in beef and dairy demand, respectively, between 2000 and 2050 (O'Mara, 2011).

There is potential to increase global food production to meet this demand, through increased crop yields and expansion of the agricultural area (West *et al.*, 2010), although Koning & Van Ittersum (2009) warn that achieving the technical potential for food production may well be hampered by social and economic factors. Most importantly, there are significant concerns that this increase in food production will be associated with (among other impacts on natural resources) increased global GHG emissions from agriculture. For example, Smith *et al.* (2007) estimate that, by as soon as 2020, global GHG emissions from agriculture will increase 38% relative to 1990 (24% relative to 2005). This would bring total emissions from world agriculture to 7.2 Gt CO_2eq yr^{-1}, with the bulk of this increase occurring in Sub-Saharan Africa, the Middle East, East Asia, and Latin America (US-EPA, 2006).

However, the extent of this increase in emissions depends on the means by which the expansion in agricultural productivity will be achieved, specifically whether it will be achieved through increases in crop and animal yields, or by means of an expansion of the global agricultural area through land use change (or both). Historically, the 162% increase in global crop production from 1961 to 2005 has been achieved by a combination of a 135% increase in global crop yields, and a 27% expansion of the agricultural area (Burnley *et al*., 2010). In recent studies, Burnley *et al*. (2010) demonstrate that, even though the historic yield improvements have been associated with increased GHG emissions, these increases were much smaller than those that would have materialised if the productivity increase would have been realised merely through expansion of the agricultural area. This means that crop yield improvements have avoided additional emissions as high as 13.1 Gt CO_2eq yr^{-1} (Burnley *et al*., 2010). Smith *et al*. (2007) estimate that the carbon dioxide emissions that has been associated with historic land use change, especially deforestation, account for 15% of global emissions and 30% of the emissions associated with livestock production in the developing world (FAO, 2006; Smith *et al*., 2007).

In a modelling study to assess the GHG impact of *future* increases in agricultural productivity, West *et al.* (2010) showed that the difference in GHG impacts of crop yield improvements and land use change will be even starker in future. This difference will be particularly prominent in regions at lower latitudes which generally have both the greatest potential for yield increases and the greatest potential for carbon stock losses arising from land use change.

As a result, there is strong international recognition that the twin challenges of Food Security and combating Climate Change are intimately intertwined, and cannot be solved in isolation from each other (e.g. Huang *et al*., 2010; West *et al*., 2010), and this realisation has led to a number of significant international developments in policy and research. For example, in 2010 the EU established a Joint Programme Initiative on "Agriculture, Food Security and Climate Change" (www.faccejpi.com), in which Teagasc is a major participant and Work Package Leader. At global level, the Global Research Alliance (www.globalresearchalliance.org), initiated by New Zealand at the Copenhagen summit in 2009, aims to coordinate global research activities to address these twin challenges. Ireland (Department of Agriculture, Fisheries and Food) is a signatory to this initiative and Teagasc represents Ireland on the Livestock and Croplands technical groups. In light of these developments and the projections on food demand outlined above, the most pertinent challenge facing agricultural policy and research is not necessarily to reduce domestic GHG emissions, rather it is to minimise the projected *increase* in *global* agricultural GHG emissions.

3.2 The concept of carbon leakage

In order to minimise the projected increase in global agricultural emissions, it is imperative that agricultural production is maximised in regions where the associated emissions are lowest. Any contraction in food production in one region in order to meet national GHG emissions reduction targets, may simply displace that production elsewhere (e.g. Andúgar, 2010). This “carbon leakage”, will result in a global net increase in GHG emission if the region where production is displaced to has a higher ‘emissions intensity’ (GHG emissions per unit product) than the region where production had contracted. This anomaly could have potentially significant impacts on net global GHG emissions.

Figure 6 shows the emission intensity of dairy and beef production for a range of geographical locations, calculated using IPCC-defined agricultural emissions (Lanigan *et al.*, 2011). It shows that emissions from South America and South Asia were almost double those of Irish, EU and New Zealand emissions, even without taking into account the effects of land use change, i.e. expansion of the agricultural area at the expense of natural habitat. If land-use emissions were to be included (with only residue burning and soils emissions allocated to the land-use change), the emissions per unit product would double for South America.

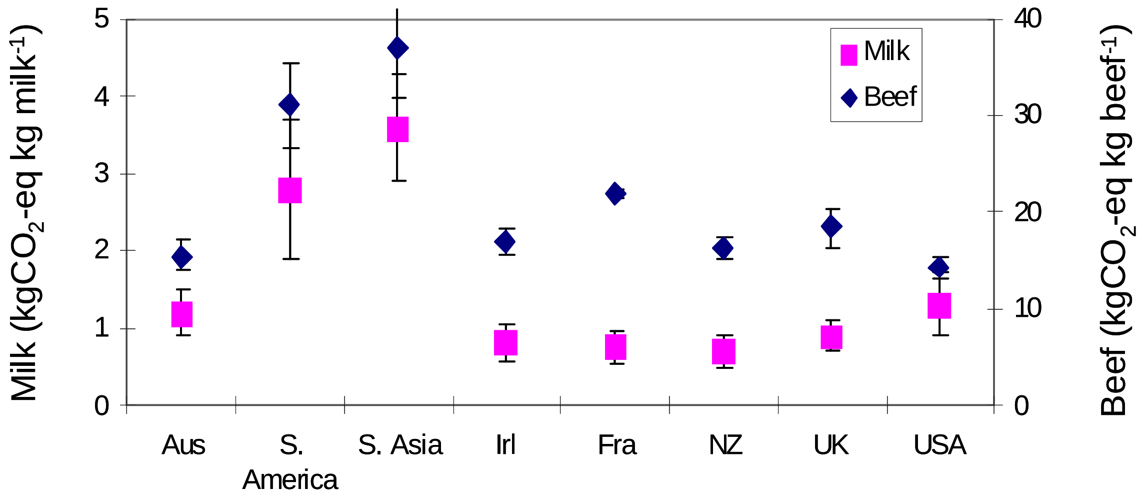
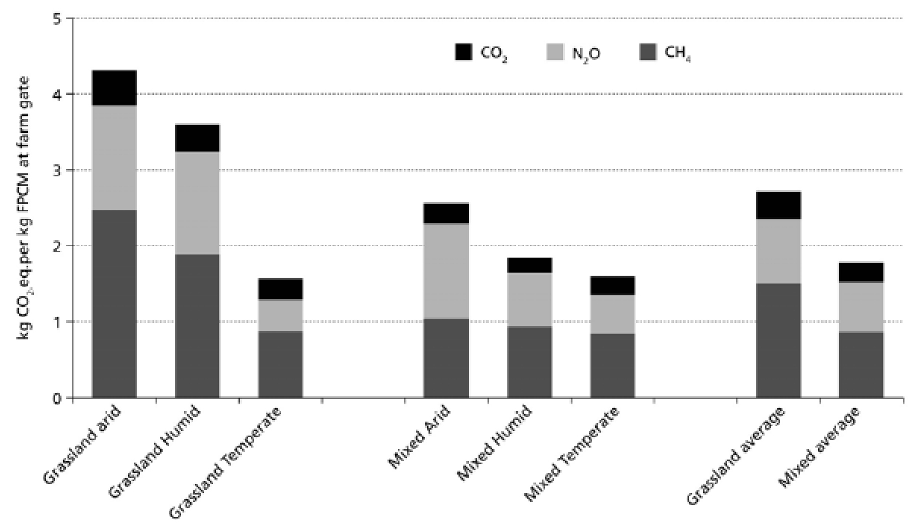


Figure 6: Total agriculture-based emission intensity for beef and dairy produce for a range of geographical locations (Lanigan et al., 2011).

These findings are corroborated by a recent report by the FAO (2010) (Figure 7), which shows that temperate grass-based systems (such as Ireland and New Zealand) have the lowest emissions per unit fat & protein-corrected milk (FPCM,) with emissions of 1.5 kg CO_2eq kg $FPCM^{-1}$. Mean emissions from tropical grassland (Latin America and South-East Asia) were 3.2 kg CO_2eq kg $FPCM^{-1}$and even higher were emissions from arid grassland systems: 5-7 kg CO_2eq kg $FPCM^{-1}$. Higher emissions were principally due to higher methane emissions that resulted from reduced forage quality. As a result, leakage of dairy production from temperate grass based systems to tropical or arid grasslands will double or treble the emissions associated with the same amount of product.

For beef production, a meta-analysis by Crosson *et al*. (2011) has shown wide ranges of variation across production systems and countries. Irish emissions varied from 18.9 – 21.1 kg CO_2eq kg^{-1} beef and compared favourably to Brazilian emissions, which were in excess of 30 kg CO_2eq kg^{-1} beef (Cederberg *et al*., 2009). This value again excluded land-use change, which would increase by between 50% and 100% depending on the proportion of land-use emissions allocated. Simple calculation based on the values presented in Figure 6 show that displacement of 50% of current Irish beef exports to South America would result in a net increase of *global* emissions by between *c.* 3.6 Mt CO_2eq per annum, equivalent to *c.* 20% of total current Irish agricultural emissions. This conservative estimate disregards emissions associated with landuse change; if these emissions were to be taken into consideration, the estimated value would be two to three times higher.



Note: Emissions related to processing and land use change are omitted.

Figure 7: Total emission intensity for dairy produce for contrasting production systems. Source: FAO (2010).

3.3 The role of metrics in achieving Food Security and combating Climate Change

The process of carbon leakage (section 3.2) arises directly as a result from the metrics employed internationally for the national GHG inventories under the Kyoto Protocol. Under the terms of this protocol, and more recently the EU 2020 Climate and Energy Package (http://ec.europa.eu/clima/policies/brief/eu/package_en.htm), absolute emission reduction targets are set for developed (Annex 1) nations. Each nation is expected to achieve these targets by decreasing emissions on a sector basis (UNFCCC, 1998). Developing countries (termed non-Annex 1) are exempt from GHG reductions in the protocol. The IPCC guidelines were developed to prepare transparent and simple inventories on a national scale and not to determine emissions or assess strategies to reduce emissions on a lower scale such as at the farm level (Schils *et al*., 2006). This has given rise to two distinct anomalies, i.e. i) it exacerbates carbon leakage and 2) it can incentivise the adoption of incorrect mitigation measures.

3.3.1 Current metrics exacerbate carbon leakage

The IPCC guidelines require GHG emissions to be reported on a territorial basis. Thus, it is necessary to estimate emissions per unit area when quantifying farm related emissions (Casey and Holden, 2005). Previous studies have reported that extensive systems produced the lowest GHG emissions per hectare relative to intensive systems (Haas *et al*., 2001; Van der Werf *et al*., 2009). However, Figure 8 shows that, when GHG emissions are quantified on a product basis, some of the intensive systems produce less emissions relative to extensive or organic systems (Williams *et al*., 2006; Sevenster and DeJong, 2008; Thomassen *et al.*, 2008), provided that excessively high levels of N fertilizer use can be avoided and that overall emissions associated with intensification are offset by higher levels of productivity (see Basset-Mens *et al*., 2009). For example, O'Brien et al. (submitted, b) compared GHG emissions from dairy systems in Ireland differing in intensity and cow genotype. The study found for the same amount of total emissions, selecting dairy systems that produce the lowest emissions per ha would lead to a 5 to 9% reduction in production relative to selecting dairy systems that produced the lowest emissions per unit of product. Thus, the current area-based approach will not lead to the highest reduction in GHG emissions possible for a given level of product.

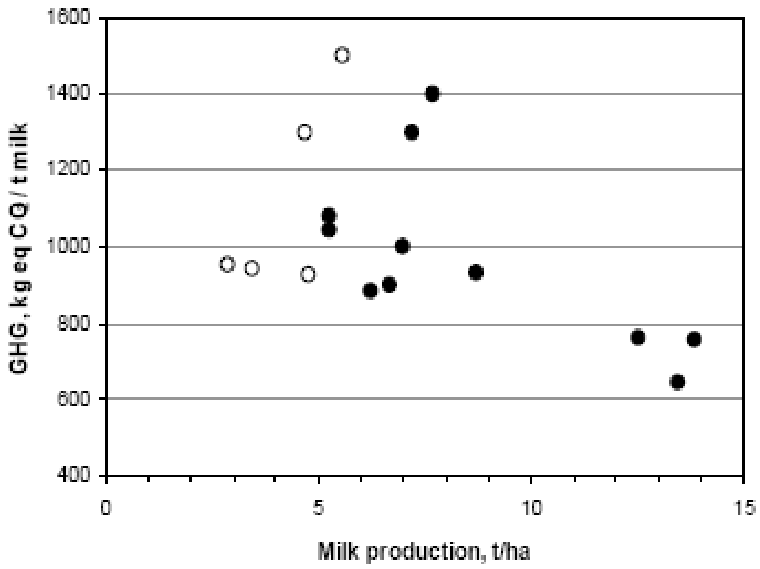


Figure 8: Estimation from literature studies of GHG emission in conventional (●) or organic (○) dairy systems as a function of milk production. Source: Lanigan, unpublished review.

As a result, the current method of reporting emissions incorrectly incentiveses extensive production systems. The consequent displacement of food production from intensive to extensive production in Ireland will inadvertently exacerbate the process of carbon leakage, discussed in section 3.2.

3.3.2 Current metric can incentivise incorrect mitigation measures

In the case of agriculture, national inventories only account for those emissions in the agricultural supply chain that are generated inside the national boundaries. Whilst the IPCC approach of dividing emissions into sectoral categories provides a consistent approach that is comparable across countries, it is not consistent with the integrated nature of agricultural production systems. As a result, a substantial portion of emissions associated with the manufacture of inputs, fuel usage and land-use change is excluded (Crosson *et al.*, 2011). In addition, emissions associated with the production of inputs arising outside of national boundaries are not considered.

Recognising this issue, systems modelling approaches, such as life cycle assessment (LCA), are widely used for farm level analysis (Williams *et al.*, 2006; Thomassen *et al.*, 2008). Unlike the IPCC guidelines, LCA is not obliged to confine the accounting of GHG emissions by sector or geographical boundaries. Instead, the accounting of emissions is restricted by the definition of system boundaries. This allows a holistic analysis of GHG emissions, which is not possible within the framework of the IPCC method.

Comparison between system approaches such the IPCC and LCA methods have found that the former approach is unsuitable for identifying strategies to reduce emissions (Schils *et al.*, 2006; O'Brien *et al.*, submitted, a). O'Brien *et al*. (submitted, a) used both methods to quantify GHG emissions from a pasture and total mixed ration (TMR) based dairy farm, as well as to estimate the emissions from nine pasture based dairy farms varying in strain of Holstein-Friesian cow (differing in genetic potential for milk production and fertility) and type of grass-based feed systems (differing in stocking rate and level of concentrate per cow). The physical performance used to quantify emissions from these farms was obtained from previously published work (Horan *et al*., 2005; McCarthy *et al*., 2007). The study found that the ranking of dairy systems emissions per unit of product were inconsistent between methodologies because the IPCC method excludes indirect GHG emissions from farm pre-chains i.e. concentrate production. For instance, using the IPCC method, the emissions per unit product, associated with confinement TMR dairy farms, were lower by 9%. However, when the LCA approach was used, and emissions from the entire supply chain were accounted for, emissions from these systems were in fact higher by 10%. These results indicate that the development of farming systems that target a net reduction in global GHG emission intensity for agriculture requires a holistic accounting approach, such as LCA.

3.4 From absolute emissions to emission intensities

Under Section 5(9) of the Climate Change Response Bill, sectoral plans must account for a) the need to promote sustainable development, b) the need to safeguard economic development, c) the need to take advantage of economic opportunities within and outside the State and d) be based on scientific research. Under these criteria, Teagasc contends that an 'absolute emissions' metric is inappropriate for the agricultural sector.

In order to address greenhouse gas emissions in the context of rising food consumption, and to reduce the risk of leakage, Teagasc, and international research, has shown that an 'emissions intensity', or 'emissions per unit product' should be adopted, taking into account the emissions arising from the entire supply chain (Leslie *et al*., 2007; del Prado *et al*., 2010; FAO, 2010; Crosson, 2011; O'Brien *et al*., submitted). This metric does not view GHG and food production in isolation and estimating emissions in this way will encourage producers to improve their productive efficiency. Previous studies have shown that increasing production efficiency has reduced GHG emissions per unit of product in the past and will also be a key strategy to reduce emissions in the future (Lovett *et al*., 2008; Capper *et al*., 2009; Beukes *et al*., 2010). Therefore, emission targets must be set per unit of product as this will encourage producers to improve their efficiency of production, thereby reducing overall emissions for a given level of production.

In addition, adoption of an emission intensity metric will allow and incentivise the industry to develop strategies to produce agricultural products with a low carbon footprint. This would facilitate harmonisation of policy initiatives to further reduce the emission intensities of agricultural produce with international consumer preferences, which favours produce with a low carbon footprint (Section 5.2). In light of Ireland’s favourable starting position in this respect, this may represent a significant potential marketing opportunity for exports.

It is evident that a significant international policy effort will be required before this change of metric can be employed at EU, or indeed global scale, though it is worth noting that such a change is currently the topic of discussion in global initiatives such as the Global Research Alliance. As an example, New Zealand, under its domestic offsetting scheme, has already proposed to alter the metric for agriculture from ‘absolute emissions’ to ‘emissions intensity’ for the purpose of internal national accounting of GHG emissions from agriculture.

4. ABATEMENT STRATEGIES FOR GREENHOUSE GAS EMISSIONS FROM IRISH AGRICULTURE

In light of the approaches to reducing *global* GHG emissions (Section 3 above), there are three pathways through which Irish agriculture can contribute to mitigating and/or reducing Ireland's GHG emissions. These are:

1. Further reduction of the emission intensity of agricultural produce (Section 4.1);
2. Offsetting emissions associated with agricultural production through carbon sequestration (forestry, grassland sequestration) (Sections 4.2 and 4.3);
3. Displacement of fossil fuels through domestic production of biofuel and/or bioenergy (Section 4.4).

4.1 Further reduction of the emission intensity of agricultural produce

Teagasc has estimated the current emission intensities of the two dominant Irish agricultural commodities, i.e. the emissions associated with the production of a kg of milk (or per kg milk solids) and those associated with the production of a kg of beef. Life Cycle Assessment was used, using input data from a variety of relevant sources, including the CSO, CMMS, industry experts and the National Farm Survey (www.agresearch.teagasc.ie/rerc/farm_surveys.asp). Both on-farm farm emissions ("direct emissions") and off-farm emissions ("indirect emissions") associated with the production of farm inputs, as well as fugitive N_2O emissions associated with ammonia volatilisation, were taken into account in the analyses.

As a result, Teagasc estimates that average emissions from dairy production systems amount to 1.13-1.15 kg of CO_2eq per kg of milk, or 15.72-16.06 kg CO_2eq per kg milk solids (Shalloo *et al*., 2010). For beef systems, total average national emissions amounted to 21.2 kg CO_2eq per kg beef carcass for suckler beef systems (Foley *et al*., in review) and 14.1 kg CO_2eq per kg beef carcass for dairy beef systems (Crosson *et al*., 2010).

Teagasc has a proactive research programme, in collaboration with Universities in Ireland and abroad, on developing mitigation measures aimed at further reducing the emission intensities associated with agricultural produce. This research programme is co-funded by DAFF, EPA, SFI and the EU Framework 7 programme and INTERREG, and includes research on animals, soils, grassland management, manure management, grazing systems, and farm management systems. Selected mitigation measures currently being evaluated by Teagasc include:

1. Improvement of genetic merit of cows (Section 4.1.1);
2. Extension of the grazing season (Section 4.1.2);
3. Reducing beef finishing times (Section 4.1.3);
4. Restructuring of the national bovine herd (Section 4.1.4);
5. Improvement of N-efficiency (Section 4.1.5);
6. Increased use of clover (Section 4.1.6);
7. Use of nitrification inhibitors (Section 4.1.7);
8. Minimum tillage techniques (Section 4.1.8).

Teagasc estimates that combinations of the mitigation measures have the *technical* potential to reduce the emission intensity (i.e. rate of emissions *per kg product*), of both beef and dairy production by up to 15-20%. Teagasc expects that, at national level, this has the potential to translate into emission intensities between 18 and 19 kg of CO_2eq per kg beef carcass for suckler beef systems and between 11 and 12 kg of CO_2eq per kg beef carcass for dairy beef systems. For dairy, it is forecast that dairy emissions per kg of milk solids sold will decline from 15.72 kg of CO_2eq to 13.15 kg of CO_2eq by 2018. Beyond 2018, present research indicates that there is potential to further reduce emissions by up to 11% (11.7 kg of CO_2eq per kg of milk solids).

However, a number of important considerations have to be taken into account in the development of mitigation measures, and in the interpretation of their potential to reduce emission intensities:

- The *impact* or total mitigation potential of each mitigation measure: this impact depends on *both* the technical potential of the measure, *and* the relevance of the measure to Irish agriculture, i.e. the number of farms to which the measure is applicable. For example, the impact of a mitigation measure may be limited to specific soil types, or to particular nutrient or grassland management regimes.

- The *cost-abatement* ratio of each measure: in principle, each of the measures is aimed at reducing the emission intensity of agricultural produce through more efficient use of natural resources (e.g. genetic merit, nutrients, grass growth potential). In that regard, these GHG objectives are fully aligned with the agronomic objective of maximising production efficiency. However, each of these measures may be associated with varying levels of cost-effectiveness. In the selection of mitigation measures, it is imperative to consider the cost-abatement ratio, i.e. the ratio of costs associated with the measure to the abatement potential of the measure (Hedlund, 2010; Schulte, 2010). This approach was successfully adopted and demonstrated by the SEAI in their recent cross-sectoral report on GHG mitigation options for Ireland (Motherwell & Walker, 2009). Cost-abatement ratios may range from cost-beneficial (net economic gain associated with the GHG mitigation measures) or cost-neutral (no net economic gain or loss), to cost-prohibitive (impact of mitigation measure does not justify economic costs).

- The potential for *on-farm verification, implementation, incentivisation and adoption* of the mitigation measure: the mitigation potential of selected measures, as identified under the controlled conditions employed in research programmes, commonly represent the *maximum* abatement potential. The total abatement potential of each measure, when applied to "real world" farming systems, is likely to be lower, and will to a large extent depend on incentivisation measures and the rate of adoption of each measure. This is further explored in Section 6. In addition, the quantity of abatement must be incorporated into national inventory reporting mechanisms. Under UNFCCC procedures, no abatement can be assigned to that measure if a measure cannot be quantified within the National Inventory Reports.

- The cumulative mitigation potential for any suite of mitigation (and / or offsetting) measures may not be additive. Any combination of measures may be synergistic, in which case the combined reduction in emission intensity will be greater than the sum of the individual reductions in emission intensity of the measures, or antagonistic, in which the combined reduction will be smaller than the sum. Furthermore, measures may be technically mutually exclusive, or indeed “competing” for land and / or farm resources. In the following sections of this submission, Teagasc is mainly reporting on the mitigation potential of individual measures in isolation; the mitigation potential of combined “suites” of measures is subject of ongoing research.

4.1.1 Improvement of genetic merit of cows

O’Brien *et al*. (2010) demonstrated that selection of cow breed, based on a combination of fertility and milk performance, reduced emissions per kg of milk solids by up to a maximum of 15%, relative to cows selected for milk only. The Economic Breeding Index (EBI) was introduced in 2001 and ranks sires on the basis of their overall economic value, taking into account their genetic merit for fertility, survival, health traits as well as milk yield. Increasing use of EBI ranked sires via artificial insemination has halted the decline in the genetic merit for fertility in the national dairy herd (Wickham, pers. comm.). In a study on a large sample of milk suppliers, O’ Donnell *et al*. (2008) showed that there was a replacement rate of 25% on Irish dairy farms. Analysis of the CMMS records in 2007 showed that 5,000 more dairy cows died / slaughtered than were born, i.e. only enough replacement animals to maintain the national dairy herd at current level. Continuing the increase in EBI is anticipated to further reduce the replacement rate on dairy farms to 22%. It is also expected that the EBI will be the key component in increasing milk solids production per cow. These increases in efficiency will be important component in reducing emissions per kg of milk solids nationally, and are expected to be cost-beneficial.

4.1.2 Extension of the grazing season

Extension of the grazing season, i.e. increasing the number of days that animals spend on grass outdoors, reduces emission intensities by reducing the quantity of stored manure, and by lowering direct enteric methane emissions from animals.

Lovett *et al*. (2008) quantified the mitigation potential of extended grazing, based on data from two studies; one study was carried out in Curtins farm in Fermoy in North Cork and the second study was carried out on Kilmaley in West Clare, both attached to Moorepark Research Centre. Data was collected over the period 1998 to 2000 on both sites. The two sites have contrasting soil types and climatic conditions with Kilmaley receiving an average annual rainfall of 1,600 mm with an impermeable soil (infiltration rate of 0.5 mm hr^{-1}), while Moorepark had an average annual rainfall of 1,000 mm with a highly permeable soil (10 mm hr^{-1}). Both systems were optimised resulting in Moorepark having a grazing season length of 250 days per year with the corresponding Kilmaley figure of 150 days per year. The results from the study were included in the Moorepark Dairy Systems Model (Shalloo *et al*., 2004) and were then fed into the GHG emission model (Lovett *et al*., 2006).

Lovett *et al*. (2008) quantified that, for every extra day dairy cows graze grass, emissions per unit of product decreased by 0.14%, using IPCC emission factors. Since for every one day increase in the length of the grazing season, there is an increase in profitability of €2.70 for every cow in the herd, this measure is expected to be cost-beneficial.

In the implementation of this measure, care should be taken to ensure that an extension of the grazing season does not lead to increased prevalence of compaction, particularly on moderately to poorly-drained soils, as this may reduce the drainage capacity of soils, which in turn may lead to higher N_2O/N_2 emission ratios from soil (Stark & Richards, 2010), which could potentially negate reductions in the emission intensity of the production systems.

4.1.3 Reducing beef finishing times

The most important source of GHG emissions from beef production systems is methane from enteric fermentation. This emission source represents 50 to 57% of total GHG emissions for suckler calf-to finish systems (Foley *et al*., in review) and therefore, strategies which result in reductions in enteric fermentation emissions result in considerably lower system level emissions. Most of these strategies involve the use of enteric fermentation modifiers i.e. dietary supplementation with e.g. lipids, yeast cultures or tannins (Beauchemin *et al*., 2008). However, these strategies are less suited to Irish pasture-based beef production systems where grazed grass represents over 60% of the total system feed budget. Attaining high average lifetime daily gains reduces days to slaughter and this results in lower absolute enteric fermentation emissions and lower enteric fermentation emissions per kg of beef carcass produced (Foley *et al*., in review). High average lifetime daily gains are also compatible with high production efficiency and profitability (Foley *et al*., in review).

Analysis carried out by Teagasc and UCD is summarised in Table 3 (Foley *et al*., in review). Average farm conditions in Ireland, based on a subset of farms representing suckler calf-to-finish farms in the Teagasc National Farm Survey (NFS) (Connolly *et al*., 2008), and research farm conditions based on Teagasc, Grange research suckler systems (Drennan & McGee, 2009) were modelled and compared with respect to productivity, profitability and GHG emissions. Two Grange systems were modelled; a calf-to-steer beef system and a calf-to-bull beef system. Stocking rate was higher for the Grange systems at 2.2 LU ha^{-1}. Additionally animal performance was higher and thus, beef output was much higher for the Grange systems. As a result of higher levels of animal performance for the Grange systems, enteric fermentation emissions were lower for these systems, relative to the NFS system.

Table 3: Comparison of National Farm Survey and Teagasc, Grange Research Farm levels of efficiency on productivity, profitability and GHG emissions

	NFS[1]	**Grange-Steer[2]**	**Grange-Bull[2]**
Stocking rate (LU ha^{-1})	1.2	2.2	2.2
Lifetime daily gain (kg d^{-1})	0.85	0.91	1.05
Beef carcass output (kg ha^{-1})	255	453	496
Farm net margin (€ ha^{-1})	-67	312	477
Enteric emissions (kg CO_2eq kg^{-1} beef carcass)	11.3	10.2	10.0
Direct emissions (kg CO_2eq kg^{-1} beef carcass)	17.1	14.8	14.2
Total emissions (kg CO_2eq kg^{-1} beef carcass)	21.2	18.0	17.4

[1]From National Farm Survey (Connolly *et al*., 2007), and representative of average farm conditions in Ireland; [2]From Drennan & McGee (2009). Representative of research farm conditions for steer and bull beef systems.

When combined with improved nutrient use efficiency, direct (those produced on-farm) and total (on-farm emissions plus emissions associated with purchases, ammonia volatilization and nitrate leaching) emissions were 15% and 18% lower for steer and bull systems, respectively. Table 3 indicates that profitability was also greater for the Grange systems; therefore, this measure is expected to be cost-beneficial.

4.1.4. Restructuring of the national bovine herd

The Food Harvest 2020 targets (Section 2.3.2) are expected to impact on the size and composition of the national cattle herd, which is likely to reduce the average emission intensity of Irish agriculture, even in absence of GHG reduction targets. In particular, the dairy output target of a 50% increase in average production volume is forecast to result in a higher proportion of dairy cows. Projections made using the FAPRI-Ireland model (Section 2.3.2) indicate that a 23.2% increase in dairy cow numbers from 1.12 million to 1.38 million head will be required. The emissions increase are expected to be offset by an associated 19.1% decrease in the number of suckler cows, which results from the displacement of suckler beef by an increase in dairy beef production. This scenario should impact favourably on the overall carbon footprint of Irish beef production as suckler beef produces 21.2 kg CO_2eq kg^{-1} beef whilst emissions associated with dairy beef are 14.1 kg CO_2eq kg^{-1} beef (Section 4.1).

Examples of the impact of herd restructuring on agricultural emission intensities include New Zealand, which increased its milk production by 68% between 1990 and 2007 (FAO, 2010). Associated with this increase was a 49% increase in dairy emissions; however, emissions from the agricultural sector as a while only increased by 12% (NZ MoE, 2007), representing a reduction in average emission intensity. This was the result of the restructuring of the agricultural sector and a large decline in sheep numbers.

4.1.5 Improvement of N-efficiency

Improvements in N-efficiency at farms result in lower N fertiliser inputs per unit product. N fertiliser applications are associated with direct nitrous oxide emissions, with IPCC inventory guidelines specifying that, in absence of data on soil-specific emission factors, 1.25% of fertiliser N is to be assumed to be lost in the form of N_2O. In addition, “fugitive” emissions of N_2O may arise from ammonia volatilisation volatilisation and leached nitrogen, 1.25% of which is assumed to be converted to N_2O outside the farm gate, or indeed outside national boundaries. Ammonia emissions arise, *inter alia*, from the landspreading of animal manures. Therefore, efficient use of nitrogen in animal manures can reduce N_2O emissions through two pathways, i.e. 1) reducing ammonia volatilisation and 2) reducing fertilizer N requirements and application rates.

In addition to reducing N_2O emissions associated with application of nitrogen fertilizer, reduced fertilizer use will ultimately reduce the high fossil fuel energy requirements for the manufacturing of fertilizer nitrogen, which can equate to approximately 60 MJ/kg N (Jenssen & Kongshaug, 2003), equating to approximately 3.5-4.0 kg CO_2eq per kg urea-N (Williams *et al.,* 2006). Under IPCC national reporting rules, these emissions are allocated to the jurisdiction where the fertilizer is manufactured. Since all nitrogen fertilizer in Ireland is imported from other jurisdictions, reduction of fertilizer nitrogen inputs on Irish farms will not translate into reported reductions in GHG emissions from Irish agriculture. However, when Life Cycle Analysis is used to quantify the emission intensity of Irish produce, these emissions *are* taken into account. Therefore, lower fertilizer application rates will reduce the emission intensity of Irish produce more than it will reduce "inventory emissions".

The last decade has seen a dramatic improvement in the efficient use of nitrogen, with average fertilizer N use on grassland falling by over 40%, from 145 kg ha^{-1} in 1999 to 86 kg ha^{-1} in 2008 (Lalor *et al*., 2010). It is important to note that, given the scale of the reduction in fertilizer usage that already been realised, further gains in fertilizer N use efficiency will be increasingly difficult to achieve.

However, recent Teagasc research has shown that there is still potential to further improve on the efficient use of organic N in animal manures. Low emission spreading techniques can be used to reduce the gaseous losses of ammonia from landspreading of animal slurries, relative to the splashplate method, most commonly used at present. Methods available include: bandspreading, trailing hose, trailing shoe, and shallow injection. For application to grassland, the trailing shoe is considered to be the application method that is most suitable to Irish conditions to reduce ammonia emissions, although similar results can also be expected using bandspreader or trailing hose methods. By reducing the losses of ammonia to the air, the N remaining in the soil that is available for crop uptake is increased, thereby resulting in a potential reduction in chemical fertiliser N use (Lalor *et al*., in press), and the associated nitrous oxide emissions.

Reducing the losses of ammonia can be achieved by 2 means (Bourdin *et al*., 2010; Lalor & Lanigan, 2010):

1. Targeting cooler and moister weather conditions that result in lower ammonia volatilisation. These conditions are generally more prevalent in the spring period.
2. Using trailing shoe application method rather than splashplate

The potential to switch application timing to spring, when ammonia losses are lower and chemical N fertilizer replacement is highest, is restricted by soil trafficability. The trailing shoe application method can help to overcome some of these restrictions, but only on soils that are well or moderately-well drained (Lalor & Schulte, 2008). Since approximately 33% of Irish soils are poorly drained (Schulte *et al*., 2006), spring application is a viable option mainly on the remaining 67% of the soils. Since 35% of slurry is already being applied in spring, it is assumed that this is occurring only on well and moderately drained soils, and that the potential for increased spring application is restricted to the remaining well and moderately well drained soils (32%). Adoption of the trailing shoe method may help to increase the application of slurry to these soils in spring.

Encouraging more slurry application in the spring period will also reduce the length of the slurry storage period, thereby reducing methane emissions from slurry storage facilities, which currently account for 2.2 Mt of CO_2eq (McGettigan *et al.*, 2010b) . This arises due to anaerobic conditions in the slurry store, and is proportional to the length of the storage period. Therefore, a larger proportion of slurry being applied in spring will reduce the average length of the slurry storage period. While the exclusion of slurry application in winter under Nitrates regulations has given rise to increased storage period for some slurry, the overall effect of applying more slurry in spring is to reduce the slurry storage period by an average 3.1 %. At present, there is no allowance in the inventory for emission reduction due to shorter storage duration. Teagasc, in collaboration with international research partners, is currently conducting research to substantiate this reduction and facilitate inclusion into future national inventories.

Teagasc has estimated that, at national level, the combined effect of changing the slurry management practices on methane emissions from slurry storage and on nitrous oxide emissions following slurry application, amounts to a maximum of 0.12 Mt CO_2eq.

Adoption of low-emission spreading technology is expensive, with purchasing costs estimated to be threefold the costs of splashplate equipment. Further additional costs include extra tractor power requirements, lower work rates, and increased running costs. As a result, the economics of low emission spreading technologies restrict their usage to contractors or large-scale farmers (Lalor, 2008). Current contractor rates for splashplate application are approximately €40/hr. Estimates of expected charges for alternative methods range towards €65 per hour.

4.1.6 Increased use of clover

White clover can supply biologically fixed N in grassland through a symbiotic relationship with *Rhizobium* bacteria. As a result, clover-based systems can reduce the requirement for mineral fertiliser application, with a 20% clover/grass pasture fixing up to 200 kg N ha^{-1} yr^{-1} (Ledgard *et al*., 2001). As there are currently no emissions associated with clover N fixation in the recent update of the IPCC guidelines (De Klein *et al.*, 2006), the consequent reduction in fertiliser requirements will reduce N_2O emissions, with every kilo of N fertiliser displaced resulting in a 0.0125 kg reduction in N_2O. Furthermore, there is growing evidence that at low rates of fertiliser application (<100 kg N ha^{-1}) there is an even greater reduction in pastoral N_2O emissions, as sward N utilisation is improved (Klumpp *et al.*, 2010; Kirwan *et al*., unpublished, see Figure 9). Indeed, the emission factor for 100 kg N applied to a pasture with 20% clover was observed to be 41% lower than that for a Lolium-only pasture.

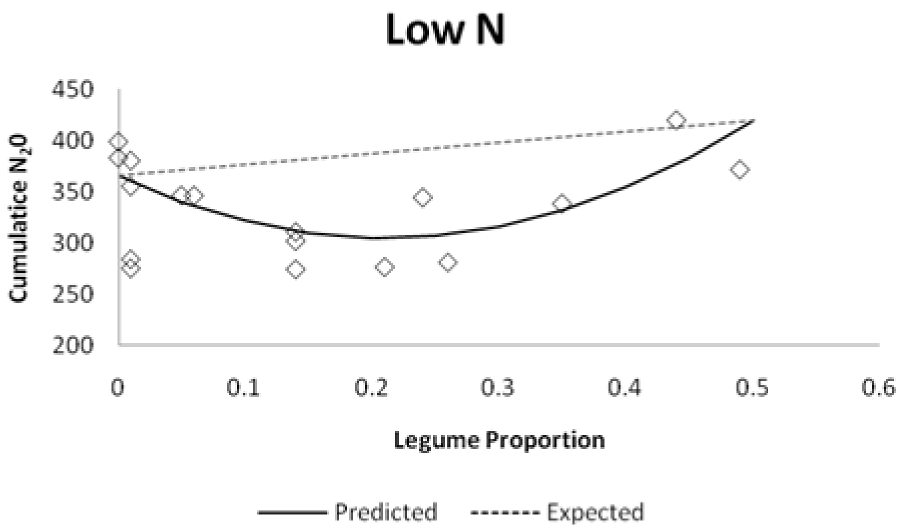


Figure 9: Cumulative N_2O emissions from pastures with different proportion of white clover. The dashed line indicates the expected emissions and the solid line the observed N_2O emissions. Source: Kirwan et al. (unpublished data).

Use of white clover has potential to substantially reduce fertilizer costs on farms (Humphreys *et al.*, 2009). This creates a strong incentive to adopt clover on grassland farms and anecdotal evidence from Teagasc REPS planners indicates that around 50% of entrants to the REPS4 scheme opted for clover as a measure. This transition does not necessarily reduce output from farms. Therefore, this measure is expected to be cost-beneficial or cost-neutral for farmers and the national economy, since all fertilizer N is imported.

A limitation is that not all soil types are suitable. Very wet, heavy and peaty soils are not suitable for clover. Little fertilizer N is being used on these soils already – so no major benefit would arise by changing grassland on these soils to clover-based swards in terms of lowering fertilizer N use.

4.1.7 Use of nitrification inhibitors

Nitrous oxide originating from grazing animals comprises 2.66 Mt CO_2eq, or 41% of agricultural N_2O emissions (McGettigan *et al.*, 2010b). Urine patches have been identified as a major source of nitrogen loss in grazing systems via leaching and gaseous emissions, with nitrogen loading rates in a single urine patch ranging from 300 to 1200 kg N ha^{-1}. One potential mitigation method to reduce the associated N_2O emissions is the use of the nitrification inhibitor dicyandiamide (DCD). DCD has been shown to reduce nitrous oxide and nitrate leaching losses and, in some cases, increase pasture production (Di & Cameron, 2002) in grazed pasture systems in New Zealand. On a per hectare basis, inhibitors are extremely effective, with reductions in N_2O emissions of between 47% - 71%, depending on the amount of N applied and on the soil type (Di & Cameron 2002, 2004, 2005; Zaman & Blennerhasset, 2010). In addition, DCD reduces N losses through leaching by 30-50%, which in turn leads to a reduction in indirect N_2O emissions.

However, the effectiveness of DCD is reduced under higher soil temperatures (>12^0C), which lead to a denaturing of the chemical. As a result, the effectiveness of nitrification inhibitors is dependent on soil type and local climate. Teagasc, AFBI and UCD are currently evaluating the effectiveness of DCD under Irish conditions.

The cost of inhibitor application is high (circa €30 per hectare per application). The economics of its use will be determined by the stocking rate, as well as soil type. It is likely that the technology will only be justifiable on soils where stocking rates are high and where the potential for reductions in N_2O emissions is large.

4.1.8 Minimum tillage techniques

In general, arable soils are a source of CO_2. Minimum tillage techniques typically increase storage of soil organic matter (SOC), relative to conventional till practices, as these techniques reduce soil erosion through the development of a litter layer. In addition, they enhance aggregate stability in the soil which slows decomposition of organic matter by providing protection within soil aggregates (Six *et al*., 2000; Lanigan *et al*., 2008b).

Table 4 shows the SOC balances and net field based emissions of contrasting minimum tillage techniques, calculated using specific data for Ireland and northern Europe (Davis *et al.*, 2010; Ceschia *et al*., 2010). These values were close to the default methodology and land-use factors (IPCC, 2006). It was assumed that SOC stocks reach a new equilibrium in a 40-60 year time period. Incorporation of the barley straw and cover crops will have a small increase in associated N_2O emissions, but this is offset by the increase sequestration potential. The reduction of bare soil, post ploughing, appears to be the most effective abatement measure. However, cover crops may be expensive and it is unclear as to whether the benefits in terms of soil N savings (from leaching reductions and input of cover crop residue N) outweigh the cost.

It should be noted that uncertainty associated with these values is large, due to inter-annual variation in sequestration activity, which can result in 100% variation in sink strength activity from one year to the next. This scale of this variation is mainly determined by climate and soil type.

Table 4: Sequestration potential and field based emissions for contrasting crops and tillage techniques.

Management	Soil C loss $t\ CO_2\ ha^{-1}$	Field N_2O emissions $t\ CO_2eq\ ha^{-1}$	Total field GHG emissions $t\ CO_2eq\ ha^{-1}$
Spring barley, ploughed	2.93	0.85	3.79
Winter wheat, ploughed	1.83	0.85	2.69
Spring barley, minimum tillage	2.20	0.91	3.11
Spring barley, min till + cover crops	0.73	1.04	1.77
Spring barley, min till + cover crops + residue incorporation	-0.55	1.16	0.61

Table 5: Total GHG emissions for contrasting crops and tillage techniques.

Management	Production and processing emissions $t\ CO_2eq\ ha^{-1}$	Total GHG emissions $t\ CO_2eq\ ha^{-1}$	Savings relative to ploughing (spring barley) $t\ CO_2eq\ ha^{-1}$
Spring barley, ploughed	2.59	6.38	
Winter wheat, ploughed	2.59	5.15	1.23
Spring barley, minimum tillage	2.46	5.87	0.50
Spring barley, min till + cover crops	2.76	4.53	1.85
Spring barley, min till + cover crops + residue incorporation	2.96	3.57	2.81

Table 5 includes all GHG emissions associated with the same crops and tillage systems. Unlike the livestock sector, where 85% of emissions are field-based, almost 50% of tillage GHG emissions result from power and fuel usage. These emissions are lowest for minimum tillage, provided no extra weed intervention or harrowing of headlands is required. Fuel based emissions for straw and crop incorporation are higher, due to extra workload requirements. However, the net GHG savings are still greater, as these fuel-based emissions are offset by the large reduction in field-based emissions.

Moving from conventional inversion ploughing to non-inversion tillage will reduce crop establishment machinery costs from €132.49 ha^{-1} to €97.28 ha^{-1} (two till runs). This costing assumes a reduction in fuel usage from 37 litres per hectare to 19 litres. However, non-inversion tillage techniques are not suitable for all soil types, are more suitable for large scale growers, and are more difficult to manage. Furthermore, over time, extra grass weed control measures and the need for occasional deep cultivation will reduce this benefit, with associated costs ranging from 0 – 67 euro per hectare, which may be needed 1 in 5 years.

Costs associated with cover crop cultivation are an additional €140 ha^{-1} (including fuel, labour, seed, management costs and loss of earnings from straw sales).

4.2 Offsetting emissions through carbon sequestration: forestry

Forestry has significant potential to sequester carbon dioxide, thereby offsetting GHG emissions from other sectors from society and contributing to climate change abatement. Currently, most afforestation takes place on private land, the majority of which is owned by farmers; as a result, forestry and agriculture are intimately intertwined. In the current national emission inventory reports, however, forestry and agriculture are reported on separately, and the offsetting of GHG emissions by afforestation is not credited to the agricultural sector, which may limit further incentivisation of farm forestry; this issue is further explored in Section 5.1.2.

Forestry can contribute to GHG abatement through a range of measures (COFORD, 2009):

1. By afforesting land (Section 4.2.1);
2. By forest management (Section 4.2.2);
3. By optimising forest productivity (Section 4.2.3);
4. By using forest products for generation of bioenergy, thereby replacing fossil fuels; this is further expanded on in Section 4.4.

4.2.1 Afforestation

Ireland currently has a forest cover of approximately 745,000 hectares, accounting for approximately 10.8% of the land area. Currently the Kyoto-eligible forests (*c.* 277,000 ha planted post-1990) sequester approximately 2.2 Mt of CO_2 per annum, while Irish forests remove approx 6 Mt of CO_2 from the atmosphere annually (Hendrick and Black, 2009). Afforestation is a key measure in Ireland's strategy to address climate change. COFORD-funded scenario analysis shows that afforestation has a significant impact on the net carbon sequestration rate of Irish forests, with increasing rates of afforestation leading to increasing CO_2 sequestration capacity from Irish forests (Figure 10). Over the five year period 2008-2012, Kyoto eligible Irish forests will sequester 11 Mt of CO_2. Current Government forest policy in Ireland aims to increase forest cover in Ireland to 17%, with a total productive forest area of 1.2 million ha by the year 2030 (Anon, 1996). Projections indicate that the required annual planting programme in the order of 22,850 ha per annum between the years 2010-2030 (457,000 ha in total), would increase CO_2 sequestration capacity to over 8 Mt CO_2 per annum.

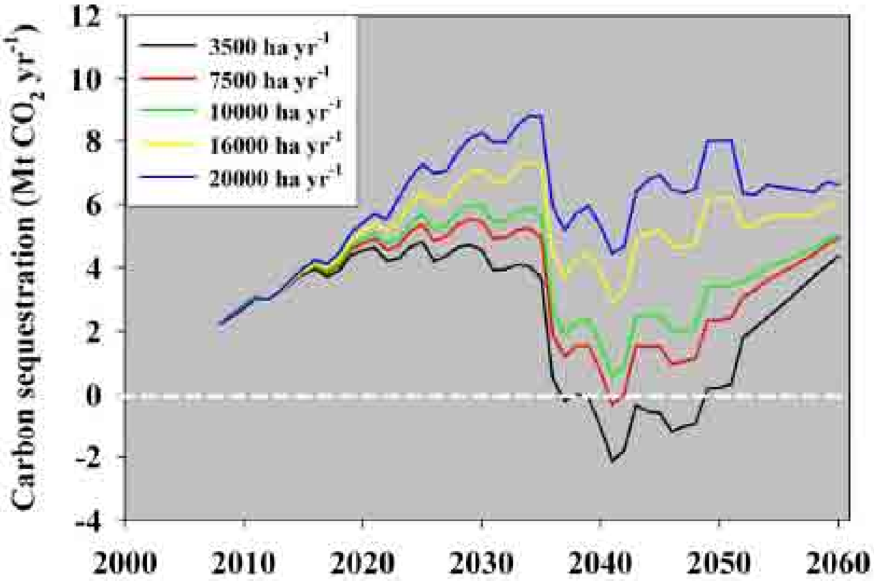


Figure 10: CARBWARE scenario analysis of the national potential for carbon sequestration by forestry, as a function of annual afforestation rates. Source: Hendrick & Black (2009).

The CARBWARE scenario analysis (Figure 10) suggests that the national carbon sequestration potential of forestry will temporarily fall sharply after 2035. This reduction reflects the substantial decline in afforestation rates after 1997, from *c.* 20,000 to 10,000 ha per annum, to rates as low as 7,000 for some years in the 2000's.

As pressure on finite land resources becomes greater, forestry has potential especially on marginal agriculture land. Forestry currently occupies 470,466 ha, or 16% of the net agricultural land area. Production in excess of $14m^3\ ha^{-1}\ yr^{-1}$ can be achieved on up to 2,440 million ha of marginal land in Ireland, with yields in excess of $20\ m^3\ ha^{-1}\ yr^{-1}$ achievable on 1,158 million ha (Farrelly, 2010). This suggests that the national target of 17% forest cover can be achieved on marginal agricultural land without affecting agricultural production.

It is essential to maintain a sustainable afforestation programme to ensure that the benefits accruing from our forests are maintained and optimised and that forests have an ongoing positive net sink effect. COFORD has indicated that afforestation above 7,500 hectares per annum is required to maintain our forests as a net carbon sink (Black *et al*., 2009).

4.2.2 Forest Management

Pre-1990 forests also sequester carbon, and contribute to climate change mitigation, but are not currently part of Ireland's forest carbon accounting regime. When Kyoto eligible forests reach harvest stage, forest management strategies that reduce GHG emissions may need to be considered. Strategies such as reforestation, continuous cover forestry systems, the reduction in the annual allowable cut, normalising the age class distribution, and the practice of sustainable forest management are all forest management initiatives that can play a role in sustaining Ireland’s forest carbon sequestration capacity. Removing 1,000 ha of forest could reduce the carbon sink by 500,000 tonnes of CO_2 (Hendrick and Black, 2009).

4.2.3 Optimising forest productivity

Targeted species selection offers the potential to optimise afforestation schemes in order to maximise their carbon sequestration potential. Results from recent research indicates productivity can be increased by targeting specific sites for forestry: yields in excess of 27 m^3 ha^{-1} yr^{-1} for Sitka spruce have be observed on deep, moist, well-aerated soils, of moderate to rich nutrient status. Average growth rates can be increased from 17 to 21 m^3 ha^{-1} yr^{-1}, by planting trees on land with some form of previous agriculture usage (Farrelly *et al*., 2009). Assuming a 15,000 ha annual afforestation programme (70% conifer), this would increase the gross annual production by 42,000 m^3, amounting to 840,000 m^3 over a 20 year period. Thus, increasing forest productivity would lead to projected increases in CO_2 sequestration capacity per unit area: based on the previous example, average CO_2 sequestration per hectares would increase by 0.5 t CO_2 ha^{-1}, or 150,000 tonnes of CO_2 ha^{-1},yr^{-1}.

4.3 Offsetting emissions through carbon sequestration: grassland

Carbon sequestration by grassland has significant potential to offset GHG emissions from agriculture. Soussana *et al*. (2004) suggested that pasture may sequester 3-4 t CO_2 ha^{-1} yr^{-1}. Permanent grassland soils may continue to sequester carbon for many decades, particularly following adoption of improved grazing management strategies. When grassland sequestration is taken into account, reductions in the emission intensities of grass-based produce could be between 30 and 70% of the total emission intensities (Pelletier *et al*., 2010; Veysset *et al*., 2010). With grass based systems dominating livestock production in Ireland, inclusion of grassland sequestration should put Ireland at a significant advantage in comparison to other major European producers. However, significant difficulties remain regarding the inclusion of grasslands as carbon sinks, as uncertainties associated with the measurement of grassland sink capacity are large (Gottschalk *et al*., 2007). Teagasc is proactive in national and European research programmes aimed at reducing these uncertainties.

4.4 Displacement of fossil fuels through domestic production of biofuel / bioenergy

The production of biofuel and bioenergy within the agricultural sector has substantial potential to offset greenhouse gas emissions in Ireland, using a number of biomass conversion technologies, of which combustion is likely to be the most important one in the short to medium term. Offsetting of GHG emissions is mainly achieved through fossil fuel displacement, although carbon sequestration and reductions in cultivation emissions, associated with production of biofuel and bioenergy, offer additional GHG abatement potential.

Displacement of fossil fuels by biofuel / bioenergy can be achieved through three pathways:

1. By domestic production of biofuel and bioenergy crops (Section 4.4.1);
2. By increased utilisation of forestry products (Section 4.4.2);
3. By increased use of bioenergy feedstocks (Section 4.4.3).

In addition, the landuse change associated with increased biofuel and bioenergy crops and forestry, will result in lower emissions of N_2O and increased rates of carbon sequestration (Section 4.4.4).

It is important to note that, under the current national inventory reporting guidelines, most of the GHG benefits of bioenergy and biofuel crops are credited to the energy and transport sectors, even though the potential to achieve these reductions can only be achieved through the agricultural sector. This anomaly is further explored in Section 5.

4.4.1 Fossil fuel displacement by biofuel and bioenergy crops

In terms of fossil fuels replacement, the GHG emissions associated with biomass and forestry-derived energy generation are principally associated with cultivation, and the release of N_2O and CH_4 on combustion. By contrast, the GHG emissions associated with gas, oil, coal or peat combustion are primarily related to CO_2 release on combustion and total emissions per unit energy produced range from 3 to 7 times higher than that for biomass, depending on the energy content and the carbon content of the fossil fuel being replaced (Styles & Jones, 2007).

Heat production from energy crops and forestry products offers a low-cost measure compared to other options, as no major plant is required. Short rotation coppice grown on 109,000 ha would provide enough energy to replace 5% of the oil, gas and electricity used in the residential market and 15% of these fuels used in the commercial market, equating to 6.6% of the total heat market (Lanigan & Finnan, 2010).

Electricity produced from the combustion of peat and coal is very C intensive (emission factors of 90 and 118 kg CO_2 GJ^{-1}, respectively). The government has established a target of 30% biomass co-firing in the three remaining peat burning power stations**.** If this target were to be achieved, almost 1 million tonnes CO_2 yr^{-1} (DOEHLG, 2007) would be displaced as emissions which arise from co-firing of energy crops are approximately 10% (Styles & Jones, 2007) of electricity emissions from milled peat, when the entire fuel chain is considered.

The substitution of petrol and diesel by indigenous liquid biofuels also has potential to play a role in GHG abatement. The production of 75,000 tonnes of biodiesel / pure plant oil and 100 million litres of bioethanol from Irish grown crops would mitigate approximately 25,000 t CO_2eq from transport emissions. While our ability to produce these crops is limited due to a number of factors, the cultivation of liquid biofuel crops promotes sustainable development within Ireland and maintains our indigenous liquid biofuel industry.

4.4.2 Fossil fuel displacement by use of forestry products

Wood fuels are second only to wind energy in terms of contribution to renewable energy generation in Ireland (SEAI, 2010). Energy from woody biomass can be generated from: first thinning of forest plantations, forest residues left on-site following final felling, co-products such as sawdust, bark and offcuts from sawmilling and board manufacture and untreated, recycled wood. There is an increasing area of forestry being thinned to provide this wood energy assortment.

The use of wood as an source for generation of electricity has increased considerably in recent years and this is set to continue as the 2015 target for 30% cofiring at the midlands power stations nears. In order to meet this target, the three power stations combined would need 900,000 tonnes of wood per annum. It is unlikely that the forest sector will fully meet this demand. In 2010, 100,000 tonnes of peat were displaced at Edenderry Power Station, which reduced net CO_2 emissions by 88,000 tonnes. This carbon saving is projected to increase tenfold to almost 900,000 tonnes if the 2015 targets were to be met at all three power stations.

In addition, wood energy will have a significant part to play in meeting the challenging target for the generation of heat energy, 12% of which is targeted to be derived from renewable sources by 2020. SEAI estimates that the planting of 10,000 ha per annum from 2008 to 2035 would make wood fuel a sustainable alternative; this would yield 4.5 Petajoules from 2030 onwards. This would result in emissions savings of approximately 0.25 Mt CO_2eq due to fossil fuel displacement. Wood fuels are generally sourced from young forests; therefore, the availability of indigenous wood fuel is dependent on maintaining afforestation levels. However, if the afforestation programme were to decelerate, the supply of small diameter wood suitable for combustion would also reduce, making wood energy unsustainable.

4.4.3 Fossil fuel displacement by use of biogas

Substantial quantities of renewable heat and electricity can be realised through maximisation of the use of our current bioenergy resources, particularly from the anaerobic digestion (AD) of agricultural by-products and energy crops. In Germany, there are approximately 4500 on-farm anaerobic digestors in operation. In Ireland, anaerobic digestors sited on farms could convert agricultural by-products and energy crops (e.g. grass and maize) to renewable energy and thus mitigate carbon emissions through the displacement of fossil fuels.

The AD process is a physical treatment process that accelerates a natural process occurring in manure and organic waste streams, and aims to maximise methane capture in controlled conditions. Methane is released from manure naturally in storage, particularly when stored for long periods of time in traditional open storage tanks. For efficient capture of methane, it is important that manure is transferred to the digester within 2 – 4 weeks of production by livestock. Smyth *et al*. (2009) found that the gross and net energy balance of grass biomethane produced in Ireland compared favourably to that of tropical biofuel production, while Hjort-Gregersen *et al.* (2007) found that net GHG emission savings of between 51 kg and 186 kg of CO_2eq are saved per ton of biomass treated in the AD process.

4.4.4 Reductions in direct GHG emissions, associated with biofuel and bioenergy production

Land use change will be necessary in order to reach our bioenergy targets and achieve substantial mitigation from bioenergy. Similar to carbon offsetting through afforestation (Section 4.3), land use change from pasture or annual cropland to perennial biomass crops has the potential to significantly offset GHG emissions by means of carbon sequestration into carbon sinks. These sinks can be either perennial woody tissue or soil organic carbon (SOC).

The conversion of arable land to bioenergy crops has been estimated to offset GHG by between 2.0 and 4.0 t CO_2 ha^{-1} yr^{-1} for Miscanthus and 1.8 – 2.7 tCO_2 ha^{-1} yr^{-1} for short-rotation coppice (Dondini *et al.*, 2010), due to the fact that croplands have been shown to be net emitters of CO_2 of between 1 – 3 tonnes CO_2 ha^{-1} yr^{-1} (Davis *et al.*, 2010).

The conversion of grassland yields lower potential for carbon offsetting through sequestration, as soil organic carbon levels in grassland are generally 30 - 100% higher than those of cropland on the same soil type, and initial carbon loss occurs due to both ploughing and extended fallow periods. If the biomass accumulation by below-ground biomass (rhizomes and roots) is included, net sequestration rates of 3 t

CO_2 ha^{-1} yr^{-1} are possible. However, reaching these rates of sequestration may take two to three years post-establishment (Hansen *et al*., 2004). The conversion of pasture to biomass crops (Miscanthus or short rotation coppice) is assumed to have no impact on long-term net C sequestration when using IPCC Tier 1 methodologies for estimating C-stocks. Indeed it was thought that, in the short-term, losses of 2 to 5 t CO_2 ha^{-1} yr^{-1} were associated with ploughing. However, recent measurements under a range of Irish soil types have shown that initial C loss after ploughing is much lower (20-100kg CO_2 ha^{-1}), and that total site preparation losses can be limited to *c*. 1 t CO_2 ha^{-1}, provided the fallow period is minimised (O'Connor *et al*., 2010).

Further savings in emissions are associated with reduced fertiliser usage following landuse change to biomass crops, as N requirements are only 25% - 50% of the N required for pasture systems. Other emissions associated with cultivation, including liming, pesticide manufacture, fuel and energy usage, are generally higher than the equivalent emissions for beef systems but lower than those for conventional arable systems, due to lower inputs and reduced requirements for annual site maintenance, particularly for Miscanthus.

5. Implementation, verification and incentivisation of GHG abatement strategies

5.1 Obstacles to achieving the GHG abatement potential of Irish agriculture

Section 4 discussed the *technical* potential of options for mitigating GHG emissions from agriculture, of opportunities for agriculture to offset CO_2 emissions through sequestration, and of opportunities for agriculture to displace imports of fossil fuels through biofuel / bioenergy production. The quantification of the potential for each of these options was largely based on studies conducted under controlled research conditions.

There are significant policy and socio-economic obstacles for agriculture to materialise its full GHG abatement potential, most of which relate to the implementation, verification and incentivisation of abatement strategies. While some of the abatement options discussed in Section 4 are synergistic with farm productivity and / or farm income, achievement of agriculture's full abatement potential will undoubtedly be dependent on financial incentivisation.

Such incentivisation could either take the form of market-driven incentivisation (Section 5.2), or be policy-driven through implementation of a domestic offsetting (DO) scheme (Section 5.3). These two mechanisms are not necessarily mutually exclusive, depending on the implementation pathway of both. However, Teagasc has identified three obstacles to the incentivisation GHG abatement strategies: the complexity of verification that is required for incentivisation (Section 5.1.1), the exclusion of carbon offsetting by farm forestry from the reported agricultural emissions (Section 5.1.2) and the exclusion of fuel displacement from the reported agricultural emissions (Section 5.1.3)

5.1.1 Obstacle 1: complexity of verification, required for incentivisation

An *a priori* requirement for either market-driven incentivisation or the implementation of a DO scheme is that all agricultural emissions are fully measured and verified. Specifically, it requires verification of the efficacy of the implementation of mitigation strategies, and their subsequent incorporation not national inventories. This verification is significantly more challenging for the agricultural sector than for other sectors, for a variety of reasons:

- GHG emissions from agriculture concern three GHG gases, i.e. CO_2, N_2O and CH_4, with multiple emission sources (and sinks in the case of CO_2) for each of these gases. Moreover, emission rates of each of these gases can show diverging responses to some of the abatement options, which was evidenced in Section 4.

- Agriculture depends almost entirely on biological processes which, by definition, are subject to natural inter-annual variation and to the complex interplay of e.g. (micro)climate and soil type (Huang *et al*., 2010). As a result, not only emission rates, but also the efficacy of mitigation measures may vary spatially (from field to field) and temporally (from year to year). In this regard, the absence of a methodology to distinguish between natural GHG processes and those derived from anthropogenic activities, presents a major challenge (Andúgar, 2010).

- This is further complicated by the highly atomistic nature of agriculture (Huang *et al*., 2010), as it consists of in excess of 100,000 small-to-medium sized enterprises. Not only does agriculture consist of a great variety of enterprises (dairy, beef, sheep, tillage, pigs, poultry, mushrooms, horticulture, farm forestry, equine enterprises, niche enterprises), each of these enterprises themselves are associated with a wide range of farm management systems. Since each individual management system impacts on GHG emissions through multiple pathways (see point 1 above), the verification of GHG emissions from agriculture is far more complex than verification of emissions from e.g. power plants or vehicles (Huang *et al*., 2010)

The resulting uncertainty about agricultural emissions is one reason why agriculture has been excluded from consideration within the ETS to date (Breen *et al*., 2010).

5.1.2 Obstacle 2: exclusion of farm forestry from reported agricultural GHG emissions

In the current National GHG Inventory Reports, “credits” for carbon sequestration are currently attributed to the Land Use, Land Use Change and Forestry Sector (LULUCF) within the non-ETS sector. While planting grants and maintenance grants are available to farmers considering farm-forestry, these historic grants do not offer an additional GHG abatement incentive. It was outlined in Section 4.3 that the carbon-offsetting potential of farm-forestry depends primarily on current and future afforestation rates. Maximisation of these afforestation rates requires that landowners (the vast majority of whom are farmers), as the dominant stakeholder of the LULUCF sector, are incentivised by attribution of carbon-offsetting credits arising from afforestation to the agricultural sector. This can be achieved through either the merging of the agricultural and LULUCF sectors for domestic purposes (as recommended by the IPCC), or through a DO scheme (Section 5.4).

5.1.3 Obstacle 3: exclusion of fuel displacement from the reported agricultural emissions

In the current National GHG Inventory Reports, “credits” for fossil fuel displacement through the domestic production of biofuel and/or bioenergy are currently attributed to the transport and energy sectors. Similar to farm forestry, increased production of biofuel and bioenergy is largely dependent on further incentivisation of farmers. Teagasc recognises that, unlike the largely anonymous LULUCF sector, the transport and energy sectors have other significant stakeholders who could justifiably seek to capitalise on these “credits” to incentivise the *use* of biofuel and bioenergy. Teagasc contends that fossil fuel displacement by biofuel / bioenergy can only be maximised if both their production and their use are incentivised, and that a DO scheme may have potential to provide an equitable mechanism to achieve both objectives simultaneously (Section 5.4).

5.2 Market-driven incentivisation

There is anecdotal evidence that adoption of GHG abatement strategies at farm level may be incentivised by consumer preferences for “low carbon-footprint” food, as facilitated by retailers. Indeed, some of the major supermarkets in the UK have now implemented carbon-labelling as a marketing strategy. This consumer driven incentivisation may provide significant opportunities for exports of agricultural produce, in light of the relatively low emission intensities associated with Irish produce. Capitalising on such opportunities by the development of a "Brand Ireland" label for Irish produce, is one of the three pillars of the vision for agriculture by 2020, set out in the recent Food Harvest 2020 report.

However, significant challenges remain to be overcome, principally relating to the verification of "carbon footprints". There is a significant risk that this verification may be associated with substantial GHG accountancy requirements (see Section 5.3.3). In addition, different retailers employ diverging methodologies to quantify the carbon footprint of their products (M Barry, pers. comm.), although organisations such as the Carbon Trust seek to harmonise such methodologies.

Teagasc, in conjunction with Bord Bia, is piloting a within-farm LCA on 200 beef farms (Crosson *et al*., 2010). While this approach is appropriate at pilot scale, the accounting requirements for full "role-out" of such an LCA is likely to be cost-prohibitive. This "role-out" could only be considered on the basis of a much simplified approach of using partial LCAs (see Section 5.4.2).

On foot of this research, Teagasc is currently preparing research on the development of a sustainability indicator for Irish produce, which will include indicators of GHG emission intensities.

5.3 The potential role of a domestic offsetting scheme to incentivise GHG abatement

Teagasc acknowledges the potential opportunities that DO can provide to the agricultural sector, and to contributing to reducing the carbon-footprint of agricultural produce, though not without a number of significant reservations and concerns.

Potential benefits include:

- DO could provide a direct financial incentive for individual farmers to proactively seek to reduce greenhouse gas emissions. Under current conditions, GHG emissions from agriculture are quantified and reported only on a sectoral basis, over which individual farmers have limited to no control.

- DO could provide a mechanism that incentivises national, rather than international purchase of carbon credits.

- DO could provide a positive and flexible tool for policy implementation, through incentivisation of low-carbon land use and/or low-carbon land management. Such market-driven stimuli would provide a more flexible and potentially more equitable approach to reducing GHG emissions on individual farms, than the implementation of top-down sectoral policies. Specifically within the context of the ongoing CAP reforms, DO could provide a mechanism to verify greenhouse gas emissions as one of the environmental objectives, expected to feature prominently in the new CAP.

- In addition, DO has potential use in the development of a "Brand Ireland" label for Irish produce, as proposed in the recent Food Harvest 2020 report (Section 5.2).

While Teagasc recognises that, in principle, Domestic Offsetting could provide opportunities to Irish agriculture and to efforts to reduce agricultural greenhouse gas emissions, the effectiveness of domestic offsetting will depend to a large extent on the method of implementation, and choice of metrics. Teagasc is particularly concerned about: 1) choice of metric 2) point-of-obligation 3) carbon-accountancy requirements and 4) requirement to avoid "pollution swapping", each of which will be discussed in more detail below.

5.3.1 Choice of metric

Teagasc is concerned that, depending on the reporting mechanisms, the use of domestic offsetting as a tool to achieve national emission targets may present challenges to achieving the objectives and vision for Irish Agriculture, as stated in the recent Food Harvest 2020 report. Teagasc is particularly concerned about the establishment of a "fixed" carbon quota for the agricultural sector. While such fixed sectoral quota may seem attractive in the short term from the perspective of national Kyoto reporting, it has been demonstrated in Section 3 of this submission that curtailing agricultural productivity in Ireland in order to achieve predetermined emission targets, may in the long term lead to *increased* global GHG emissions from agriculture through carbon-leakage.

This carbon-leakage does not necessarily exempt agriculture from the need to contribute to reducing global GHG emissions; however, it is Teagasc's position that the choice of metric is of great importance to ensure that national GHG reductions are not negated by associated increases in global GHG emissions. As the food market is a global market (and Ireland exports the vast majority of its produce), it is of greater importance to reduce the GHG-emissions *per unit of product* (e.g. emissions per kg beef / per kg milk solids) than it is to reduce the national GHG emissions from agriculture per se. Teagasc has a proactive research programme to develop farm, animal and grassland management strategies to reduce this carbon-footprint, summarised in section 4.1.

It is worth noting that New Zealand has adopted a similar, per-unit-product approach to domestic offsetting in the agricultural sector. It is also worth noting, however, that adoption of a similar approach for Irish agriculture may present challenges to the reconciliation of domestic offsetting with national reporting of GHG emissions and internationally traded credits; solutions to these challenges require further in-depth analyses.

5.3.2 Point of obligation

An important consideration in the development of a domestic offsetting scheme is the spatial scale at which the "point of obligation" is applied; this choice of the "point-of-obligation" will have far-reaching consequences on the implementation and effectiveness of any domestic offsetting scheme. Any of the four approaches outlined below should be given careful consideration, and Teagasc is willing to contribute further to these considerations through research and technology transfer.

Option 1: sectoral scale

The benefit of a point of obligation at sectoral level is a considerable reduction in individual carbon-accounting requirements. However, using this approach it would be challenging to provide direct financial incentives for individual farmers to reduce the carbon-footprint of their output. In addition, adoption of this approach has the potential to lead to conflicts of interests between different sectors in view of the allocation of carbon-credits, e.g. the agricultural sector and the energy and transport sectors regarding the credits associated with the production of bioenergy and biofuel crops, respectively (Section 5.1.3).

Option 2: individual farm scale

Such incentives would be readily available using the alternative approach of implementing the point-of-obligation at farm level; however, depending on farm enterprise, this latter approach may be associated with significant, and potentially prohibitive carbon-accountancy requirements (see Section 5.3.3).

Option 3: co-operative scale

A third alternative is to selectively facilitate farm co-operatives to trade carbon credits for shared initiatives such as anaerobic digestion of e.g. slurry.

Option 4: processor level

It is worth noting that New Zealand has adopted an approach in which the point-of-obligation is at primary processor level, where the main processors are allocated a carbon quota that includes the emissions of their suppliers. The potential benefit of adopting this approach is that it provides a flexible mechanism to align and integrate national government targets with existing consumer and corporate goals. However, the structure of New Zealand’s primary processing industry is significantly different from the corresponding industry in Ireland, and the implications of this in an Irish context require further research and analysis.

5.3.3 Carbon-accountancy requirements

Teagasc has concerns about the significant carbon-accountancy requirements that may be associated with a domestic offsetting initiative at farm level, depending on farm enterprise type. Teagasc expects that for *some* farm enterprises, particularly bioenergy and biofuel production, the accountancy requirements may well be justified by the scale and scope for carbon offsetting and the associated contribution to reducing national GHG emissions. However, Teagasc expects that for other farm enterprises, particularly the livestock sector, the accountancy requirements will be significantly more complex, impractical, or inequitable, as outlined below.

Biofuel and bioenergy

For bioenergy and biofuel enterprises, Teagasc expects that the carbon-accountancy requirements will be relatively low and straight-forward. These will mainly involve the areas of bioenergy and biofuel crops on farms, and the associated coefficients for carbon-sequestration by these crops, as derived from ongoing empirical research by Teagasc and the Higher Educational Institutes. As a result, Teagasc anticipates that the ratio between tradable carbon-credits and carbon-accountancy requirements will be favourable for these enterprises.

Farm forestry

For farm forestry, Teagasc expects that the carbon-accountancy requirements will be higher, as carbon-offsetting processes by forestry operate at decadal, rather than annual time-scales (see Section 4.2). Therefore, any accountancy schemes for farm forestry are likely to have to account for, among other factors, the age-profile of forestry stands.

Tillage and livestock enterprises

For other enterprises, particularly the livestock industry, Teagasc is concerned that the carbon-accountancy requirements will be exponentially more complex, and that the ratio between accountancy requirements and incentivisation of carbon-reducing farm management practices may be unfavourable.

Section 4.1 demonstrated that there is no single “silver bullet” to reduce GHG emissions from tillage and livestock enterprises, and that reductions can only be achieved through an integrated suite of simultaneous farm management options. In isolation, the impact of each of these options will be subtle, and moreover, in many cases specific to soil type, farm type, and local climatic conditions. For example, reductions in nitrogen fertiliser use through increased efficiency may reduce nitrous oxide emissions on individual farms; however, the extent of such nitrous oxide reductions may differ by orders of magnitude between individual farms, as this is dependent on soil drainage, which may vary between individual fields.

A second significant factor that adds complexity to the establishment of carbon quota and credits on these farms is movement of livestock and feedstuffs between farms; this would require a temporal partitioning of any lifecycle analysis associated with these animals and/or feedstuffs. It is paramount that an equitable carbon-accounting scheme for the livestock sector would require that such subtle between-farm differences are accurately and verifiably accounted for.

Therefore Teagasc is concerned that there is an inherent risk that the resource requirements for a detailed accountancy scheme may well prove to compete with resource requirements of the actual mitigation actions that are required. In other words, in the case of livestock enterprises, time spent on counting carbon may well compete with time spent on cutting carbon.

5.3.4 Requirement to avoid "pollution swapping"

As with all environmental policies, any domestic offsetting scheme should *a priori* negate the potential for "pollution swapping", where reductions in GHG emissions from agriculture would be associated with other, negative environmental side-effects. Examples include manure management measures such as aeration which may significantly reduce methane emissions while increasing ammonia and/or nitrous oxide emissions (Amon *et al*., 2005; Chadwick, 2005). At the same time, synergistic mitigation measures have also been reported, both for nitrous oxide and ammonia, such as reduction in dietary crude protein (Meade *et al*., 2011; Bourdin *et al*., 2010) and for nitrous oxide and nitrate leaching (Di & Cameron, 2004a; Dennis *et al*., 2009). Other examples include the conversion of land-use to biofuel production, which is subject of ongoing Teagasc research.

5.4 Proposed solutions to achieve the GHG abatement potential

While, at this point in time, Teagasc has no in-depth view on the optimum design or operation of a carbon-accountancy system for domestic offsetting, it would like to offer the following elements for consideration:

5.4.1 Phased roll-out of domestic offsetting across the agricultural sector

As outlined in Section 5.3, agricultural systems differ in complexity, and also in the extent to which they could meaningfully contribute to a domestic offsetting scheme. As a result, Teagasc expects that, across agricultural enterprises, there will be considerable variation in the ratio between the potential for carbon-trading and accountancy requirements. Therefore, Teagasc advises that any domestic offsetting schemes is rolled out on a phased basis, starting with agricultural sectors for which carbon LCAs have been well-established, and that have the highest potential for carbon offsetting. At this point, Teagasc has not conducted a full quantitative analysis of the aforementioned ratio between the potential for carbon-trading and accountancy requirements, but expects that this ratio will be highest for enterprises that include the production of biofuel and/or bio-energy crops, farm-forestry, and will be progressively lower for the tillage and livestock sectors.

5.4.2 Partial v. full LCAs

It is Teagasc's view that any domestic offsetting scheme can only be practical if it is based on partial, rather than full carbon LCAs. LCAs for individual farms are extremely complex, and subject to very large uncertainties, due to between-farm variations in soil type, animal breeds, farm management and farm facilities, and uncertainties with regard to emission factors (Section 5.1.1). Therefore, the establishment of full LCAs for individual farms will be laborious, time-consuming, subject to large uncertainties, and therefore difficult to verify. Moreover, full LCAs may incur issues surrounding equitability, since local geoclimatic conditions may inherently invoke different levels of GHG emissions between individual farms that are outside the farmer's control.

Therefore, Teagasc recommends that any domestic offsetting scheme is based on partial LCA, that aims to quantify and account for a selective number of *changes* in

GHG emissions only, and that carbon credits are based on changes in farm practices / landuse, rather than on absolute and full carbon quota for each individual farm. However, this approach is not without pitfalls either, and requires careful selection of mitigation options that are included in a partial LCA. Selection of these measures requires an *a priori* system analysis, to ensure that individual mitigation measures are not negated by “negative side-effects”. For example, any N-based emissions avoided during manure storage may subsequently be emitted during landspreading of the same manure (Amon *et al*., 2005).

5.4.3 Careful selection of mitigation options

While reduction in agricultural GHG emissions per unit product requires a mosaic of solutions, there is wide variation in the extent to which individual mitigation options can individually contribute to this reduction. Moreover, there is wide variation in the potential costs, or, in selected cases, potential cost-saving, associated with individual mitigation options. It is paramount that any domestic offsetting scheme, based on a partial LCA (as discussed in 5.4.2 above) should prioritise the accounting of mitigation options that:

a) have the largest potential to reduce GHG emissions per unit product;
b) are cost-effective or cost-beneficial;
c) are readily verifiable using farm management data that is readily available and does not require additional measurements on individual farms;
d) do not have negative “side-effects” elsewhere within the agricultural system that are not accounted for.

In this light, it is worth highlighting the potential role of advice and training and education in any domestic offsetting scheme. Teagasc has experience with cost-effectiveness analysis of environmental measures in general, e.g. for GHG mitigation options and for water quality mitigation options (Schulte *et al*., 2009). In our experience, mitigation options aimed at increasing resource efficiency are the most cost-effective options, as they simultaneously reduce requirements for external inputs (and therefore reduce costs), and emissions to the environment. As each farm differs in its external resource requirements, education and direct advice are often the most effective tools to maximise efficiency on individual farms. To facilitate this education and advisory effort, Teagasc is currently developing an on-farm “carbon calculator”, which aims to help advisors identify GHG abatement strategies for individual farms. While the impact of education and advice *per se* may be difficult to quantify, Teagasc recommends that this should be considered as a mitigation measure in its own right in any domestic offsetting scheme.

6. ADAPTATION TO CLIMATE CHANGE

6.1 Impact of Climate Change on global agriculture

The extent of future climate change will be primarily driven by varying potential trajectories of global GHG emissions, arising from population and economic growth. This will in turn influence the response of agriculture to changing climate conditions at regional and global scales. The biophysical effects of climate change will primarily influence agriculture via alterations in plant growth, with alterations in water availability, nutrient availability, increased temperature and elevated CO_2 all affecting total yields and crop/sward quality (Parry *et al*., 2004). Whilst elevated CO_2 may induce some additional C sequestration (Hungate *et al*., 1997), the effects of elevated temperatures and fluctuations in water availability on emissions and plant physiology could significantly reduce yields (Jones *et al*., 2000; Lanigan *et al*., 2008a).

In addition, climate change may reduce the efficacy of mitigation strategies. For example, high temperatures and prolonged water stress during the summer of 2003 caused a considerable number of grassland and forest C sinks to turn into carbon sources, with the overall result that European ecosystem sequestration was reduced by over 30% (Ciais *et al*., 2005; Reichstein *et al*., 2006). In addition, prolonged drying of histosols (peatlands) will lead to increased C loss and reduction in carbon sinks (Renou & Wilson, 2008).

6.2 Impact of Climate Change on Irish agriculture

However, the effects of climate change on Ireland in the medium term are predicted to be much less severe than effects on both continental Europe and worldwide in general. Parry *et al*. (2004) ran simulations using four IPCC climate scenarios (IPCC, 2007) and projected that while productivity was severely reduced in South America and Africa, effects were less pronounced in parts of North America and North-western Europe, including Ireland. Therefore, the relative importance of Irish production potential to global agricultural production may increase as the effects of climate change on agriculture become more pronounced.

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 *et al*., 2008), which may have implication for the total abatement potential of extended grazing. 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 Connaught and Northwest Ulster by the 2050s and little impact on dairying in the South-West. 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 *et al.*, 2008). In addition, shifts from fungal to insect pests of crops and animal are likely to occur (Olesen & Bindi, 2002).

6.3 Impact of Climate Change on Irish forestry

Climate change is predicted to have more pronounced impacts on forests, through increased frequencies of forest fires and damaging insect and disease attacks. In the UK, there is increasing concern over the number of outbreaks of novel pests and diseases in forestry and arboriculture. These pests and diseases could compromise the ability of woodlands to adapt and further compromise meeting the challenges of climate change. In addition, increased frequency and duration of strong winds can have dramatic effects on timber supply in a relatively short time period.

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.

6.4 Research on adaptation to Climate Change

Quantification of the potential impact of climate change on carbon sequestration, nutrient dynamics, soil processes, grass growth and animal performance is integral to Teagasc’s research programme, since the vast majority of its research projects measure and incorporate the effects of inter-annual climatic variation. This is further strengthened by Teagasc’s proactive participation in European and global carbon monitoring networks, which facilitate direct access to data across a large range of climatic zones. Specifically, Teagasc is deeply involved in the modelling of future climatic and mitigation effects on both grassland sequestration and enteric fermentation emissons under a new large-scale Framework 7 project (AnimalChange).

In addition, Teagasc has initiated, and is currently conducting projects on risk assessment and mapping of the potential impact of climate change on the prevalence of selected pest and diseases, and on yields in willow cultivation.

7. CONCLUDING REMARKS

It is important that any actions at policy, sectoral or individual farm level, aimed at abatement of GHG emissions from agriculture, are considered within the wider global context of sustainable food, fibre and biofuel/bioenergy production. In this submission, Teagasc has already emphasised the intricate interactions between achieving the dual objectives of global food security and abatement of anthropogenic greenhouse gases. In particular, it is imperative to a) produce food as GHG-efficiently as possible and b) to maximise global production whilst limiting the conversion of native land to agricultural use. In addition, it is imperative to take into consideration other, equally important sustainability services that are provided by agriculture, such as the provision of clean water, the provision of habitats for above and belowground biodiversity and the management of landscape amenities for tourist and domestic purposes. In this regard, it is not only important to avoid direct "pollution swapping" between these sustainability functions (Section 5.3.4); in the long term, all of these functions are expected to compete with each other for finite land resources.

The finite nature of land resources dictates that, in the medium to long term, a spatially explicit approach to sustainable land management may be required. The combination of soils and climate is the dominant factor in determining the potential of any location to contribute to each of the sustainability functions. As a result, different approaches to sustainability may be required in different regions, with the aim to simultaneously maximise each of the sustainability functions at national level, including the production of food, fibre and biofuel/bioenergy.

Through its research, advisory and technology transfer activities, Teagasc is committed to generating and contributing the knowledge, data and expertise that is required to the ongoing development and implementation of the vision for "smart, green growth" of the agricultural sector in Ireland, set out in Food Harvest 2020.

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