Agri-Food and Biosciences Institute ®

The Potential Impact of Greenhouse Gas Mitigation Policy on Agri-Food Sectors in Northern Ireland

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Executive Summary

This preliminary report presents quite lot of necessary analytical detail in addressing the potential economic impacts in the agri-food sector of meeting greenhouse gas (GHG) abatement targets in Northern Ireland (NI). In the absence of information on specific policies that would be used to meet the target, this report applies two approaches to analyse the links between economic activity and emissions in NI focusing on agriculture and food&drink processing. First, the observed changes to emissions since 1990 are examined, to provide insight as to the potential for future reductions. Second, a GHG levy is imposed using a comprehensive economic model of the NI economy based on data from the year 2005 to identify the potential impact of imposing additional costs on sectors related to their emissions intensity i.e. emissions per unit of economic output. The exercise has resulted in the identification of eight key issues for consideration in the context of developing climate change policy to mitigate GHG emissions in NI.

1. The level of GHG emissions generated within NI (according to the IPCC reporting system) reduced by approximately 15% between 1990 and 2010. To achieve the target of 35% below 1990 emissions in 2025 as laid out in the NI Executive's Programme for Government, another 23.8% reduction will be needed in the period 2010-2025.

2. The already observed 15% reduction by 2010 in NI's GHG emissions was driven by the economic downturn and high energy prices, a phenomenon at odds with simultaneous economic rebalancing and further GHG abatement in the future.

3. Agriculture is a major source of GHG emissions, particularly non-carbon emissions closely related to animal numbers and land management. The fundamental link between livestock output and emissions, and the limitations on substituting towards 'greener' inputs, contrasts with other sectors such as electricity. Land is unique in that it can be either a source of emissions or a means of abatement by serving as an emissions sink.

4. Reductions in agricultural emissions in the past have been largely attributed to CAP reforms, especially decoupling of support payments, implementation of the Nitrates Directive and the high fertiliser price. However, the potential of these drivers in further emissions reduction is very limited. New drivers to further the GHG mitigation process are urgently needed.

5. Economic modelling indicates a local climate change levy on economic output, based on the emission-intensity of each sector, negatively impacts the competitiveness of the local economy. This is mainly due to the movement of production away from emission-intensive and also export-intensive sectors in Agri-food.

6. Without technological progress contributing to GHG mitigation, economic measures, such as the levy based on emission-intensity in this study, are either too expensive or

infeasible for meeting aggressive national GHG reduction targets. In a unilateral framework, economic instruments have limited environmental benefit because production would shift to other sectors, or to high-emitting sectors outside the region. Developing new technology, and the application of existing technology that is economically viable, should be taken as a priority in policy development.

7. The analysis illustrates the strong linkages between agriculture and food&drink processing. Therefore, any climate change policy regime targeting emissions associated with agriculture will need to be sensitive to repercussions further along the chain.

8. It is important to note that given the uncertainties in the data available caution is needed in interpreting the results. To clearly answer the questions discussed above, more time for further research and modelling is needed. Specifically, decomposing the linkages between GHG emissions and local economic activity in greater detail and certainty, improving our representation of the economy beyond agri-food, expanding the detail of trade flows, explicitly capturing expectations through dynamics, and modelling the impacts of specific abatement technology.

Introduction

Climate change policy encompasses different measures that are used for mitigating and adapting to climate change. Commonly mitigation in this context refers to reducing the intensity of radiative forcing (i.e. Greenhouse Gases, GHGs) in order to reduce the effects of global warming. The accumulation of GHGs in the atmosphere is regarded as the primary factor driving long-term global warming and more frequent occurrences of extreme weather events. Adaptation refers to the preparation for the consequences of higher temperatures and extreme weather.

This report focuses on analysing the economic costs of policies related to the reduction of GHGs in Northern Ireland (NI). In essence, this is, *ceteris paribus*, a cost comparison between economic activity with and without the policy option considered. The reduction of GHGs often involves adopting technology to lower emission-intensity, reducing emission sources, or, improving emission sinks through land use change and reforestation. Therefore, an intuitive and direct way to estimate the mitigation costs is likely to include costs from two major sources: (1) adopting new technologies in GHG mitigation and (2) changes in economic structure induced by switching technologies. In this sense, the economic costs of mitigation will not only include the direct costs of implementing new technology but the indirect costs of economic structural changes.

In general NI has followed efforts made at international, EU and UK levels. In 2012, the Northern Ireland Executive's Programme for Government revised its target to reduce greenhouse gas emissions in 2025 from 25%, in an earlier program (PfG, 2008-11), to at least 35% from 1990 levels (PfG, 2011-15). Subsequently a cross departmental action plan was developed and amended to ensure the target is achieved by specifying locally relevant mitigation measures (Cross – Departmental Working Group on Greenhouse Gas Emissions Feb 2011; Cross-Departmental Working Group on Climate Change May 2012).

There are difficulties in estimating the economic costs of GHG mitigation in NI for the years 2025 and 2050 using an intuitive and direct way, mainly because of the uncertainties surrounding GHG inventory figures and long-term projections. Particularly uncertain, are projections related to technology adoption and changes to the local economic structure towards future periods. AEA Technology (the UK company providing GHG emissions for the UK government) suggested that the level of uncertainty (variation coefficient) in the 2009 NI inventory figure published in 2011 is much higher than for the UK (39% compared to 16%), mainly because a larger percentage of GHG emissions in NI are from the agricultural sector (Cross-Departmental Working Group on Climate Change May 2012). In terms of technology-based abatement, there are very limited data available for the effectiveness of current policy measures in terms of technical and economic feasibility, as well as for the development and use of new technology for the period post 2015. More importantly, the impacts of wide-reaching technology change on economic structure are difficult to predict.

Bearing all these factors in mind, this study looks at two aspects of the economic cost of GHG mitigation in NI. First, it explores what has been achieved in terms of technological advancement to reduce GHG emission-intensity in different economic sectors and the likely reasons behind the changes. Second, we examine the likely costs if an economic measure, namely a levy on output based on emission-intensity, is used to reduce the NI emission-inventory. Throughout the study, the focus is on agriculture and food&drink processing sectors.

1. Changes in GHG emission-intensity: expectation and reality

The level of GHG emissions in NI has fallen by 15% in the period between 1990 and 2010. A large percentage (60%) of the reduction occurred from 2005 to 2010 (See Table 1). To achieve the NI cross-departmental GHG reduction target for 2025, (i.e. total GHG emission-inventory being less than 15.58 mt CO_2e in 2025), NI will need to reduce GHG emissions by 30.8% of the 2005 level, and 23.8% from the 2010 level.

The three major GHGs in the NI emission-inventory are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). In 2010, these gases accounted for 71%, 14% and 13% of total GHG emissions in NI, respectively. Comparing emission structure with other UK regions, NI has a relatively higher percentage of non-carbon emissions (29%) and emissions from residential and public sectors (20%). This reflects the fact that in NI agriculture is relatively more important than in the UK as a whole, and that the industrial sectors of the economy are less developed.

Most of the net reduction in GHG emissions between 1990 and 2010 occurred after 2006, a period of economic recession. Of the three major GHGs, larger reductions occurred in CH_4 and N_2O emissions relative to CO_2. On the other hand, most of the decrease in carbon emissions happened in the last 5 years.

By national communication sector (used in official GHG emission-inventory reporting), agriculture is a top contributor to NI emissions largely due to CH_4 and N_2O emissions associated with livestock and soils. In 2010, enteric fermentation, manure management, and agricultural soils generated 90% of total agricultural emissions (National Atmospheric Emissions Inventory 2012). Therefore, to meet ambitious abatement targets, non-energy emissions intrinsic to agricultural production will need to be addressed.

Table 1: GHG emission levels (Mt CO_2e) and changes (%) for selected years in NI

				Period Change		Annual Change	
	1990	**2005**	**2010**	**1990-2010**	**2005-2010**	**1990-2010**	**2005-2010**
By Greenhouse Gas							
Carbon	16.74	16.27	14.66	-12%	-10%	-0.7%	-2.1%
CH4	3.68	3.05	2.86	-22%	-6%	-1.3%	-1.3%
HFCs	0.00	0.31	0.38	885%	23%	42.3%	4.3%
N2O	3.51	2.90	2.56	-27%	-12%	-1.6%	-2.4%
SF6	0.001	0.013	0.005	164%	-60%	7.8%	-16.9%
By National Communication Sector							
Agriculture	5.85	5.75	5.26	-10%	-8%	-0.5%	-1.8%
Business	2.71	2.45	2.30	-16%	-6%	-0.8%	-1.2%
Energy Supply	5.31	5.36	3.95	-26%	-26%	-1.5%	-5.9%
Industrial Process	0.76	0.42	0.17	-77%	-59%	-7.1%	-16.2%
Land Use Change	0.05	0.01	0.11	93%	1,896%	3.3%	82.0%
Public	0.46	0.17	0.21	-54%	25%	-3.8%	4.5%
Residential	4.36	3.53	3.82	-13%	8%	-0.7%	1.6%
Transport	3.33	4.38	4.20	26%	-4%	1.2%	-0.8%
Waste Management	1.10	0.48	0.44	-60%	-10%	-4.5%	-2.1%
Total Net Emissions	**23.94**	**22.54**	**20.46**	**-15%**	**-9%**	**-0.8%**	**-1.9%**

Sources: NAEI 2012

The emission figures reported in Table 1 are mainly caused by human economic activities and so are linked to economic output to reflect the complexities of the human economic system. Emission-intensity, or, emissions per unit economic activity, is regarded as the key to reducing emissions overall. Changes to emission-intensity in NI between 2005 and 2010 for the agricultural and food&drink processing sectors are reported in Table 2. More detailed information on changes in individual agricultural sectors is included in Table A of the Appendix.

Agriculture appears to have much higher emission-intensity than food&drink processing, as agriculture produces considerable non-energy emissions related to land and livestock, while energy-related emissions are the major source of emissions in food&drink processing. In 2010, the emission-intensity of agriculture was 5.3 ktCO_2e/£m output compared to 0.04 ktCO_2e/£m in the case of food& drink processing, and 0.26 ktCO_2e/£m in the overall economy.

Between the years 2005 and 2010, agriculture's GHG emission-intensity reduced by 9.4% compared to reductions in food&drink processing and total production of 23% and 22%, respectively. The changes to emission-intensity are largely related to changes in real output. In agriculture, both emissions and output have fallen in the period. In the case of food&drink processing, as well as total production, emissions fell while output expanded. CO_2 emissions (largely energy related) only accounted for 4% and 3% of agricultural emissions in 2005 and 2010, respectively. Therefore, the relatively smaller reduction in agriculture's emission-intensity is likely related to the changes in non-energy emissions in the period between 2005 and 2010. Further research to link the change in agricultural emission-intensity to changes in emission sources is needed.

Table 2: Changes in output, emissions, emission-intensity in 2005 and 2010

	2005			2010			2010/2005
Sector	**Output (£m)**	**Emissions ($ktCO_2e$)**	**Intensity ($ktCO_2e$/£m)**	**Output (£m)**	**Emissions ($ktCO_2e$)**	**Intensity ($ktCO_2e$/£m)**	**Intensity Change (%)**
Agriculture	937	5,422	5.78	929	4,883	5.25	-9.2%
Food&drink processing	2,765	140	0.05	3,416	133	0.04	-23.0%
Agri-food (sum of above)	3,703	5,562	1.50	4,346	5,016	1.15	-23.2%
Total Production	**48,376**	**15,915**	**0.33**	**52,672**	**13,519**	**0.26**	**-22.0%**

Note: (1) outputs above are at 2005 constant price and when available producer price indices (PPI) otherwise retail price index (RPI) are used to make output comparable between years; (2) agriculture in the table is the total of sectors included in calculation (see Appendix Table A)

Source: own calculations based on NAEI (2012) and NI Input-Output Tables

Currently no quantitative study is available linking these observed changes in emission-intensity to specific drivers in NI. The changes are likely related in part to the implementation of climate change policy, but also changes to wider economic policy and prices. Some climate change policies have been developed internationally and applied at the EU / UK level such as the Renewable Energy Directive and Renewable Obligation Certificates (ROC), the EU Emissions Trade Scheme (EU ETS), and, the UK 2050 climate change target and associated carbon budgets. The policy recommendations at the NI level, which are outlined in the cross-departmental action plan, mainly rely on the adoption of existing technological measures to reduce the emissions-intensity of production activities in the economy. Observed changes to GHG emissions (particularly CO_2 emissions) in the period examined here (1990 to 2010) are closely related to changes in economic structure and the energy market. Since 1990, NI's economic structure has moved towards services and manufacturing with relatively lower emission-intensity and fossil fuel prices have increased considerably in the second half of last decade.

In terms of NI agriculture, reforms of the Common Agricultural Policy (CAP) in the last decade, particularly the decoupling of payments, has significantly impacted the beef and sheep sectors in terms of animal numbers and real output which reduced by over 10% in the period 2005-2010. This contributed to reduced CH_4 and N_2O emissions in the agricultural sector. The implementation of the Nitrates Directive (EC, 1991) may have contributed to the reduction of N_2O emissions. However, market-related drivers such as fertiliser and crude oil price hikes are also responsible for less intensive use of fertilisers and energy, which resulted in lower emissions. All these factors may have contributed to a faster reduction in carbon emissions later on compared to earlier on in the period 1990 to 2010. Limited by data and time, we are still not able to quantify the factors affecting changes in emission-intensity for individual sectors specifically.

2. Economic costs of GHG mitigation policy: a counterfactual analysis

Given the complexity of economic-environmental linkages, particularly those associated with the interdependency amongst economic sectors, a computable general equilibrium (CGE) modelling approach is used to estimate potential economic costs of climate change policies. The CGE model takes account of linkages between different economic sectors and behaviour changes in economic activities and it is a standard way to systematically estimate the economic costs of different economic and environmental policies for the overall economy.

In order to explore the potential economic and environmental impact of imposing climate change policy at the NI level, a counterfactual analysis of different scenarios was carried out using production and emissions in 2005 as our baseline. Based on the polluter pays principle, each sector in the economy is penalised equally for each unit of GHG emissions (based on global warming potential) by imposing an output tax, or climate change levy, based on emission-intensity.

The calculation of the emission-intensity tax rate for each sector is based on the average emission-intensity in NI. Thus a sector with average emission-intensity faces a penalty of 1% of output value, while a sector with twice the average rate of emissions per unit value of output faces a 2% tax on output value. In the 2005 base year used in the analysis, the average emission-intensity in NI was approximately 466 ton CO_2e emitted per £m of output. The dairy sector in the baseline emits 3.62 times the average, so faces an extra cost of 3.62% of its output value under the policy. The emission-intensity tax rate calculated for each sector in agriculture, and the wider-economy is provided in Table B in the appendix.

Note that it is not our intention to propose a climate change tax in this study. The emission-intensity tax above can be interpreted as either a penalty for emitting GHGs or the cost of abatement. As information on the specific cost of GHG reductions for different sectors is not available, particularly in the case of agriculture, for this analysis we assume the abatement cost is the same across the economy and impose the same rate of tax for each sector.

The tax rate reflects the relative emission-intensity in the base year, but the base rate (1%) is arbitrary. Therefore, the base rate is varied to test the sensitivity of the results to the level of taxation. The base rate of 1% is referred to as the 'Medium' tax, and 'Low' and 'High' tax rates are calculated by multiplying the 'Medium' rate by 0.5 and 1.5 respectively. The relative rates between sectors remains the same, but the overall level of taxation decreases or increases (See Table B in appendix for more information).

The CGE model is also sensitive to how flexible producers are in terms of responding to the policy shock. In particular, the model is sensitive to whether or not capital is free to flow between sectors. It is reasonable to assume that immediately after imposing the policy capital stock in agriculture and elsewhere in the economy will remain at similar levels as in the baseline (a short-run response), but become more flexible to move between sectors over time (a long-run response). The impact of the policy shock is calculated using different assumptions about capital mobility to reflect the short-run and long-run in order to allow for comparison. Therefore, six scenarios in total are explored: the three levels of taxation each run under short and long-run assumptions regarding capital.

Table 3 shows the emissions in the baseline and each of the six scenarios in agriculture, food&drink processing, and the rest of economy expressed in ktCO_2e. The change in emissions calculated as the percent of the baseline value is also reported for the case of agri-food (agriculture and food&drink processing combined) and the total NI economy. In the short-run framework, with capital assumed to be fixed at sector-specific levels, beef emissions only change by -2% of the baseline, even when faced with the 'High' tax rate of 9%. In the same scenario, dairy faces a tax rate of 5.4%, but does not abate any emissions. This is because dairy is relatively more capital-intensive than beef, so fixing capital in the sector keeps production, and therefore emissions, close to baseline levels. As capital becomes more flexible in the long-run scenarios, there is a larger response in the dairy sector. In the long-run 'High' tax scenario (dairy taxed at a rate of 5.4% and beef 9% of its output value), dairy emissions change by -24% and beef by -26% from the baseline. The net change in agri-food emissions is between less than -1% and -2% in the short-run, and between -10% and -23% in the long-run. Total emissions, including the rest of the economy, change between -1% to -2%, and -2% to -5% of the baseline in the short and long-run respectively.

Table 3: Emissions in the baseline and change under each scenario for agriculture, and food-drink processing (KtCO_2E)

Sector	Baseline	Short-run / capital fixed			Long-run / capital mobile		
		Low tax	Med tax	High tax	Low tax	Med tax	High tax
Cereals	228	-0.1	-0.3	-0.6	-14.4	-27.9	-40.4
Potato	50	-0.2	-0.3	-0.5	-0.9	-2.0	-3.1
Horticulture	73	0.0	0.0	0.0	0.2	0.3	0.4
Dairy	1,676	0.1	0.1	0.1	-155.3	-291.2	-408.6
Beef	2,199	-13.1	-28.2	-45.8	-248.4	-428.1	-563.2
Sheep	501	-18.0	-35.3	-51.9	-57.1	-100.0	-133.4
Pig	96	-1.0	-2.0	-3.0	-2.7	-5.5	-8.3
Poultry-egg	52	0.1	0.2	0.3	1.1	1.9	2.4
Food&drink processing	114	0.0	-0.1	-0.1	-4.3	-7.8	-10.6
Rest of economy	17,686	-5.3	-11.5	-19.1	42.2	72.0	92.2
Total (sum of above)	**22,678**	**-37.5**	**-77.5**	**-120.7**	**-439.7**	**-788.2**	**-1072.6**
% change of total		0%	0%	-1%	-2%	-3%	-5%
Agriculture and food&drink processing (agri-food)	**4,992**	**-32.2**	**-65.9**	**-101.6**	**-481.9**	**-860.2**	**-1164.8**
% change of agri-food		-1%	-1%	-2%	-10%	-17%	-23%

Note: (1) Baseline figures in the table for each sector are those for 2005. The NAEI reported NI GHG inventory was allocated to each sector according to drivers of emissions and other information such as animal numbers and wastes, and uses of land, fertiliser and energy. (2) There are differences between baseline figures in this table and Table 2 for total emissions for two reasons. Table 2 is calculated based on NAEI (2012) and this table on NAEI (2011). Land use conversion is excluded in this table and analysis due to the great uncertainty associated with the impacts of this process.

Changes to production levels expressed in £m for each scenario are provided in Table 4. In the 'High' tax case, the long-run change in agri-food emissions (-23%) comes at a cost of reducing agri-food production by £579m (-14% from the baseline). The change to production levels across scenarios clearly illustrates the link between agriculture and processing in the NI economy. In the short-run, food&drink processing production changes by less than 1% of the baseline even under the 'High' tax level. However, in the long-run, as capital is free to move between sectors, food&drink processing decreases by £147m - £351m (5 - 12% of baseline production) depending on the tax level.

Exports in the baseline and under each scenario are shown in Table 5. In the long-run, dairy exports change -13% to -36% from the baseline depending on the tax level. Food&drink processing exports suffer moderately in the short-run (decreasing less than 1% of the baseline) and seriously over the long-run (-7% to -17%). In the 'High' tax level case, the long-run change in agri-food exports (agriculture and food processing combined) is -18% of the baseline, a decrease of £326m. Note that under the 'High' tax long-run scenario un-processed dairy and beef exports decrease more than 30%.

Table 4: Agriculture and food&drink processing output in the baseline and each scenario (£m)

Sector	Baseline	Short-run / capital fixed			Long-run / capital mobile		
		Low tax	Med tax	High tax	Low tax	Med tax	High tax
Cereals	39	-0.03	-0.06	-0.10	-2.49	-4.81	-6.96
Potato	17	-0.06	-0.11	-0.17	-0.32	-0.68	-1.06
Horticulture	62	0.00	-0.01	-0.03	0.15	0.25	0.31
Dairy	454	0.02	0.02	0.02	-42.08	-78.90	-110.73
Beef	362	-2.15	-4.64	-7.54	-40.86	-70.41	-92.63
Sheep	71	-2.55	-5.01	-7.38	-8.11	-14.21	-18.96
Pig	62	-0.63	-1.28	-1.93	-1.72	-3.53	-5.35
Poultry-egg	167	0.28	0.57	0.87	3.46	5.93	7.76
Food&drink processing	2,840	-4.73	-10.21	-16.53	-147.24	-261.54	-351.82
Agri-food production (sum of above)	**4,075**	**-9.85**	**-20.73**	**-32.78**	**-239.21**	**-427.89**	**-579.43**
% change agri-food		0%	-1%	-1%	-6%	-11%	-14%

Note: (1) the database used to calibrate the CGE model includes Single Farm Payment values, assuming they are capitalised into land values, therefore the output level will be different than that used in the Table 2 in the report. (2) Baseline figures are those for the year 2005, published by DARD.

Table 5: Agriculture and food&drink processing exports in the baseline and each scenario (£m)

Sector	Baseline	Short-run / capital fixed			Long-run / capital mobile		
		Low tax	Med tax	High tax	Low tax	Med tax	High tax
Cereals	2	0.01	0.01	0.02	-0.20	-0.39	-0.56
Potato	1	-0.01	-0.01	-0.02	-0.03	-0.07	-0.10
Dairy	112	-0.08	-0.16	-0.25	-15.69	-29.29	-40.88
Beef	7	-0.03	-0.06	-0.11	-1.29	-2.28	-3.05
Sheep	15	-1.86	-3.58	-5.16	-3.06	-5.41	-7.24
Pig	5	-0.11	-0.22	-0.33	-0.26	-0.52	-0.78
Poultry-egg	36	0.02	0.04	0.06	0.79	1.30	1.62
Food&drink processing	1,631	-3.46	-7.51	-12.17	-115.74	-205.38	-275.82
Agri-food exports (sum of above)	**1,808**	**-5.52**	**-11.50**	**-17.96**	**-135.47**	**-242.02**	**-326.80**
% change agri-food		0%	-1%	-1%	-7%	-13%	-18%

Note: (1) most agricultural products are exported after some kind of processing, the ‘dairy’ exports refers only to exports of raw milk and calves, whereas milk products such as skim milk powder, butter, etc. appear in the ‘food&drink processing’ exports. (2) the baseline data are for 2005 from various DARD publications.

The impact on welfare in the NI economy can be investigated through the changes to factor incomes, or, Gross Value Added (GVA) under each scenario. Table 6 illustrates the effect of declining factor prices under the emission-intensity tax regime, showing the change (%) in income to each factor compared to the baseline. There is a larger impact on GVA related to capital and land in the long-run compared to the short-run, although the level of impact is much more pronounced in the case of land. This makes sense considering the most emission-intensive sectors in agriculture are also the most land-intensive (cereals and ruminant livestock), so taxes on output produced in those sectors have a significant negative impact on land values.

Table 6: Relative change (% of baseline) in factor income (Gross value added)

Factor	**Short-run / capital fixed**			**Long-run / capital mobile**		
	Low tax	**Med tax**	**High tax**	**Low tax**	**Med tax**	**High tax**
Labour	-0.16	-0.33	-0.50	-0.07	-0.16	-0.28
Capital	-0.41	-0.83	-1.24	-0.50	-0.95	-1.37
Land	-4.78	-9.42	-13.95	-11.73	-20.13	-26.43

3. Discussion and conclusions

1. With changes in government policy and the economic environment, NI has achieved a reasonable reduction in the level of GHG emissions. By examining the IPCC reports, one can see that the NI GHG emission-inventory has reduced approximately 15% between 1990 and 2010. To achieve the cross departmental target of 35%, another 23.8% reduction from the 2010 level will be needed in the period 2010-2025. This basically requires a speed of abatement twice as fast as was experienced in the last twenty years to achieve the government target by the deadline.

2. Given that the NI economy needs to be further developed to rebalance towards a larger share of private-sector activity, the recent cross-departmental target may be tough to achieve. The first 15% of the current reduction in the IPCC inventory was driven by the economic downturn and high energy prices, phenomena coinciding with the fast reduction of carbon emissions between 2005 and 2010. Therefore, the same level of abatement cannot be expected if economic development is successful. Another issue to consider moving forward is that many technical measures which are easy to adopt have already been adopted, so without the development of new technology and economic incentives, the speed of abatement will slow down in the coming period.

3. Agriculture in NI is one of the major sources of GHG emissions, particularly non-carbon emissions. CH_4 and N_2O, are closely related to the number of animals, a key capital input

to livestock production that is very difficult to substitute for other, less emission-intensive, inputs (Philippidis, Bourne *et al*. 2012). Given the importance of agriculture in the local economy, particularly the dairy and beef sectors, care is needed in designing GHG reduction policy to avoid damage to these sectors.

4. Reductions in agricultural emissions in the past have been largely attributed to CAP reforms, implementation of the Nitrates Directive and the high fertiliser price. However, the potential of these drivers in further emissions reduction is very limited. New drivers to further the mitigation process are urgently needed.

5. Assuming that 2005 technology is in place, our CGE modelling analysis suggests that an emission-intensity output tax (or levy) imposed on all sectors within NI negatively impacts the competitiveness of the local economy. Also, results indicate that the environmental gain in terms of reducing the NI emission-inventory is small considering the economic implications. This is mainly due to the movement of production away from export-intensive industry, and overall reductions in production due to the indirect and induced income effects triggered by the tax. Dairy and food&drink processing exports are severely restricted in the long-run scenarios. Therefore, it is important to consider the impact of NI-level climate policy in an international context, such that the impact on NI exporters compared to competitors in the world market is seriously considered. If we are to meet NI's abatement target there would need to be significant additional development of global markets for products and services produced locally to help compensate for the loss of competitiveness in traditionally strong exporters in the agri-food sector.

6. Without technological progress contributing to GHG mitigation, economic measures (i.e. changing the current economic structure with taxes and quotas) will be either too expensive or infeasible for meeting aggressive national GHG reduction targets. This however does not mean that economic measures are unimportant, as they are useful for providing signals to trigger technology change via investment decisions and to help avoid unintended consequences of changing technology, such as emission backfire effects.

7. The changes to production levels in our CGE analysis illustrate the strong linkages between agriculture and food&drink processing. The cost of reducing agriculture's emissions is jointly carried by the processing sector: even though the emission-intensity tax is levied on agriculture, processing decreases production by between £147m and £351m (5-12%) in the long-run. Therefore, any climate change policy regime targeting emissions associated with agriculture will need to be sensitive to the economic (income and employment) repercussions further along the chain.

8. It is important to note that given the uncertainties in GHG inventory figures and possible measurement errors in other indicators used in this report, caution is needed in interpreting the results. To clearly answer the questions discussed above, more time for further research is needed. Specifically, linkages between GHG emissions and the local economy, and the drivers contributing to emission changes need to be further examined and quantified. The CGE model needs to be improved by (1) incorporating the rest economy in more detail, (2) more specific representation of trade flows linking to the world market, (3) incorporating the time dimension to better capture expectations and investment decisions, and (4) modelling the impacts of specific abatement technologies across sectors.

Appendix

Table A: changes in emission-intensity in agricultural sectors in 2005 and 2010

	2005			2010			2010/2005
	Output (£m)	Emissions ($ktCO_2e$)	Intensity ($ktCO_2e$/£m)	Output (£m)	Emissions ($ktCO_2e$)	Intensity ($ktCO_2e$/£m)	Intensity Change (%)
Cereals	15.9	268.8	16.90	19.4	314.7	16.19	-4.2%
Potatoes	13.3	58.2	4.38	15.7	88.0	5.61	28.1%
Horticulture	58.4	57.1	0.98	43.1	32.1	0.75	-23.7%
Dairy	343.4	1923.2	5.60	338.6	1767.8	5.22	-6.8%
Beef	243.3	2437.7	10.02	219.7	2147.6	9.78	-2.4%
Sheep	43.7	495.0	11.33	38.1	369.6	9.70	-14.4%
Pigs	61.7	104.4	1.69	71.5	98.2	1.37	-18.8%
Poultry&Eggs	157.7	77.8	0.49	183.7	65.0	0.35	-28.3%
Agriculture	937.4	5422.1	5.78	929.9	4883.0	5.25	-9.2%
Food	2765.8	140.1	0.05	3416.4	133.3	0.04	-23.0%
Agri-food	3703.2	5562.2	1.50	4346.2	5016.3	1.15	-23.2%
Production	48376.5	15915.2	0.33	52672.4	13519.4	0.26	-22.0%

Note: (1) output figures are from DARD publications but those for 2010 are deflated by producer price index (2005=100) to make it consistent over time. (2) Emissions for each sector are allocated according to drivers of emission in NIEA (2012) and other information such as animal numbers and wastes, the sectoral uses of energy, land, fertilisers etc. The information is derived from Annual Business Inquiry, Farm Business Survey and various censuses. (3) The irregularity in emission intensity for potato in 2010 is mainly related to its increased use in fertiliser in the year.

Table B: Rates used to impose an emission-intensity policy (only agriculture listed here)

Commodity	Low	Medium	High
Cereals	2.87	5.74	8.60
Potato	1.45	2.90	4.35
Horticulture	0.37	0.74	1.11
Dairy	1.81	3.62	5.43
Beef	3.01	6.02	9.03
Sheep	3.48	6.96	10.44
Pig	0.71	1.43	2.14
Poultry and egg	0.10	0.20	0.30
Economy average	0.5	1.0	1.5

Note: the tax rate is calculated based on relative emission-intensity of domestic production

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