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# **Benefits and Costs of Methane Emission Reduction in the Irish National Herd**

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## **Abstract**

In this paper, we compare many of the widely available estimated global benefits of abatement with the costs to Irish agriculture, as estimated by the CAPRI model. We apply the model to Ireland only, in a simple comparative static simulation, and assume fixed prices. We focus more on methane reduction than GWP reduction as a whole, because most of the discussion regarding global warming from agriculture in Ireland has focused on methane. Our results suggest that the costs of methane abatement to the farming sector do indeed outweigh the global benefits, except in the case of very small methane abatements. However, if one also factors in the gains to society of the FEOGA budget rebates, then all losses disappear, and in fact net financial gains occur. We conclude that this may have implications for the design of methane reduction policies.

**Keywords:** methane, abatement costs, agriculture, Ireland

**JEL Classification:** Q18, Q51

## **1. Introduction**

In the late 1990's scientific consensus was growing that human activities were having a major impact on the global climate systems, possibly causing a warming of the earth that could result in significant impacts such as sea level rises, changing weather patterns, forced changes in agricultural production and land use, and the spread of tropical pests and diseases. Following the signing in 1992 of the United Nations Framework Convention on Climate Change (UNFCCC) little progress had been made on the pledged reduction of greenhouse gases by the major industrialised nations that had signed the agreement.

It was for this reason and the heightened public concerns over possible environmental impacts, that it was agreed by the parties to the UNFCCC treaty to enter into negotiations on a protocol to establish legally binding limitations for greenhouse gas emissions. At a conference held in December 1997, in Kyoto, Japan, the parties to the UNFCCC agreed to a historical protocol to reduce greenhouse gas emissions by harnessing the forces of the global marketplace to protect the environment (UNFCCC, 1997). The Kyoto Protocol set targets for the reduction of greenhouse gases by 2008-2012, which included an 8% cut from 1990 levels for the European Union (EEA, 2000). EU member states commitments were differentiated to reflect their different circumstances. Ireland committed to a net growth in emissions of 13% on 1990 levels, reflecting the high levels of actual and expected economic growth in the country at the time of agreement. However, current conservative estimates predict that Ireland will overshoot its emissions quota by 13-14 million tonnes of CO<sub>2</sub> equivalent under a "business as usual" scenario by 2008 (Convey and Roberts, 2000).

Agriculture in a developed country such as Ireland uses intensive tillage systems, high energy and large fertilizer applications, resulting in fossil-fuel based emissions, reductions in soil carbon, and emissions of nitrous oxides. In addition, animal herds emit high methane levels. Accompanying this is the fact that environmental policy within agriculture and its effects on the revenue and output of Irish farmers is an important issue in Ireland due to the relative strength of the agriculture sector. Even though Ireland's

sustained strong economic performance since the mid-1990s benefited other sectors more than agriculture, the agri-food sector as a whole still accounted for an estimated 8.9% of GDP in 2003. Primary agriculture remains more important to the Irish economy than is the case in most other EU member states. Irish agriculture accounted for 2.5% of GDP at market prices in 2003 in Ireland, compared to an EU average of 1.7%.

Given the relative strength of the agriculture sector in the Irish economy and the high level of associated greenhouse gas emissions from the sector it is not surprising that the Irish government is targeting large reductions of methane emissions from this sector as one of the main ways of Ireland meeting its agreed upon Kyoto commitments. Irelands National Climate Change Strategy (NCCS) (Department of the Environment, 2000) turns Ireland commitments under the Kyoto Protocol into a programme for action. From an agricultural viewpoint, it outlines the government's objective to reduce methane emissions from the national herd by 1.2 Mt CO<sub>2</sub> equivalent. The strategy will require methane (CH<sub>4</sub>) reduction roughly equivalent to a reduction of 10 per cent in the national herd on projected 2010 levels.

In this paper the costs to the agricultural sector of such a 10% methane reduction from 2001 levels are estimated, and compared to some well-known estimates of the global benefits from reduction. Also in the paper, a marginal abatement cost curve is reported for Ireland and for two regions within the country. The paper uses the marginal abatement curve to compare the estimated costs of different-sized cuts in emissions with the estimates of the potential global benefits. It is found that the costs to Irish agriculture of almost any methane emission abatement above 1.25% or so outweigh all the estimates of global benefits. However, once FEOGA budgetary rebates resulting from abatement are taken into account then all the methane reductions modelled in this paper appear to be potentially self-financing.

The paper limits itself to presenting abatement scenarios for 2001. This year is the most recent, at the time of writing, for which data on emissions is available for Ireland. However, policy-makers interest is more likely to lie in examining the effects of abatement for 2008-2012, the years for which Kyoto targets are set. Proposed decoupling of the CAP, and potential changes to WTO policies, are likely to affect how these targets

can be met. This issue is not examined in this paper, but modelling the effects on emissions of decoupling and WTO agreements is an obvious issue for ongoing and future research.

We begin the paper with a brief examination of the literature on the costs and benefits of abatement. This is followed by some descriptive statistics on emissions in Ireland and by a summary discussion of the methodology commonly used to calculate benefits of abatement. We go on to introduce the CAPRI (Common Agricultural Policy Regional Impact) model, which is used to calculate the marginal abatement cost curves. Results are presented and comparisons made in the following section, and in the final section the main conclusions are drawn.

## **2. Literature Review**

The relative global warming effects of methane, nitrous oxide and carbon dioxide are approximately known in terms of climate change (Schimel et al., 1996) as are their climate change impacts (Fankhauser, 1995; Reilly and Richards, 1993; Tol, 1999; Tol et al., 2001), but as Tol et al. (2003) points out, knowledge on the costs of methane emission reduction is scant (Hourcade et al., 1996; Kruger et al., 1998; Watson et al., 1996). Little research has been carried out on the costs of methane emission reduction in Ireland either. Much of the international literature on the topic involves rough estimates of the direct costs of selected emission reduction options (Hourcade et al., 1996 and Hogan, 1993).

Blok and De Jager (1994) is one of the earliest studies of the costs of methane emission reduction. It is a bottom-up study for the Netherlands. It is difficult however to compare the Netherlands to Ireland (with regard to methane emissions) because of the former's dense population, intensive agricultural production methods and a comprehensive distribution system for natural gas. In another earlier study, Adams et al. (1992) have examined the costs of various methane and nitrous oxide reduction strategies in the United States. For methane reduction, they studied reduced rice fertilization, reduced high-energy feed rations, and a tax on beef consumption. To reduce methane emissions by one million tons, they found costs ranged from about \$600 per metric ton CH<sub>4</sub> for

reduced rice fertilization to nearly \$4,000 for the beef tax remedy. Other relevant studies include Hayhoe et al. (1999) which looks at the trade-offs between methane and carbon dioxide emission reduction for the U.S. until 2010 and Godal and Fuglestvedt (2002) which focuses on the effect of different ‘global warming potentials’ estimates on cost effective emission reduction policy in Norway.

A more recent paper by Tol et al.’s (2003) analyses the trade-off between methane and carbon dioxide emissions, and estimates the optimal amount of methane emission reduction. This is done for various assumptions about desirability, the international regime, and the costs of methane emission reduction. The cost-benefit analysis is carried out with The Climate Framework for Uncertainty, Negotiation and Distribution Model (FUND) for nine major world-regions. This is an integrated assessment model of climate change. Tol et al. show that, in the short term, methane emission reductions could provide an opportunity to limit the costs of climate change control, and hence should have a prominent place in the policy mix. The authors find that for emissions between 1995 and 2004 the marginal costs of methane is approximately \$89/tCH<sub>4</sub>.

Interest in the area of climate change has significantly increased in the Irish economic research arena<sup>1</sup>. Environmental issues such as greenhouse gas emission abatement are also increasingly becoming a more important aspect of Irish agricultural reform (Binfield et al., 2001). Research focused on greenhouse gas emission reduction in Irish agriculture however, is limited to a number of more recent studies. One such study by McQuinn and Binfield (2002) used an econometric model of the Irish agricultural sector (FAPRI-Ireland) to project emissions of greenhouse gases as outlined in the Kyoto Protocol from the Irish agri-economy. The model was used to project values of key agricultural variables for the 2001-2010 time period. Using environmental coefficients these values were then converted into greenhouse gas emission levels. Two series of projections were examined – a baseline or “no policy change” projection and a specific scenario, which reduced World Trade Organisation (WTO) export subsidy levels. The difference between these two results was then used to compute a marginal cost to the Irish agricultural sector of reducing emissions.

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<sup>1</sup> See for example McCoy and Scott (2001), FitzGerald et al.(2002) and Conniffe et al. (1997).

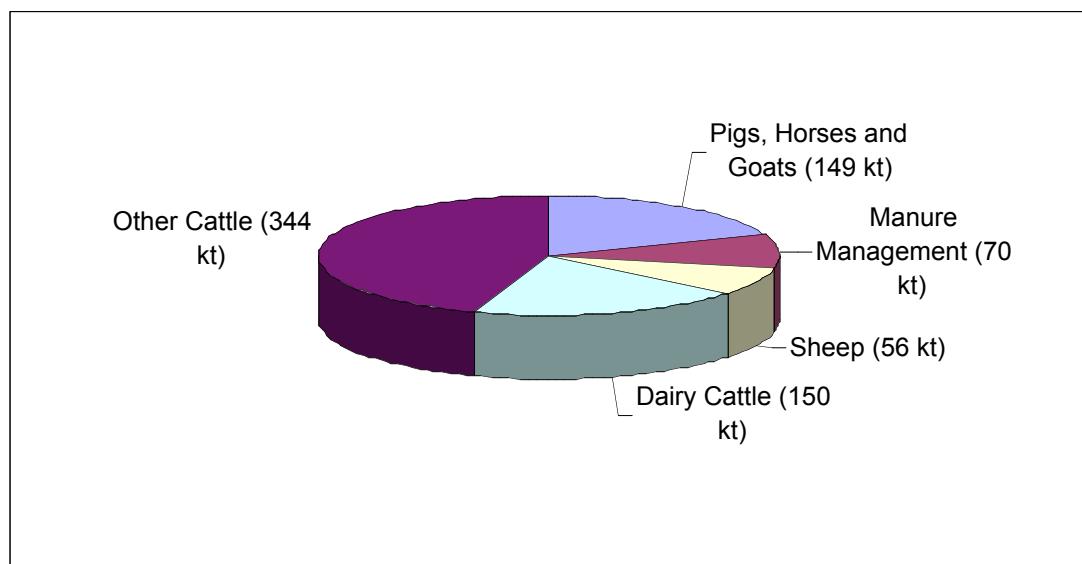
The results from the McQuinn and Binfield study showed that emission levels from Irish agriculture are set to fall over the period 2001 to 2010. This reduction is due mainly to falling suckler cow numbers in the beef sector and the lower projected intensity of production in this sector. Under the WTO export reduction scenario McQuinn and Binfield estimated that the average cost of reducing greenhouse gas emissions to Irish agriculture would be €4.87 per tonne of CO<sub>2</sub>. In a follow on paper, Behan and McQuinn (2002) present results from the same FAPRI-Ireland econometric model of Irish agriculture and combine them with those from a model of Irish forestry, in order to calculate the net emissions of carbon dioxide equivalents from the Irish agricultural and forestry sectors. Overall, assuming no policy change, Behan and McQuinn calculate total net greenhouse gas emissions from Irish agriculture and forestry to be 16.5 Mt CO<sub>2</sub> equivalents in 2010. This represents an eight per cent decline from the level recorded in 1990.

Other research in the area of emissions from Irish agriculture includes Convey and Roberts (2000). This paper reviews two environmental challenges facing Irish farmers, global warming and acidification. Part of Convey and Roberts analysis involves looking at reducing emissions from enteric fermentation by reducing the size of the Irish dairy herd. They find that the cost of abating methane emissions by reducing dairy herd sizes ranges from £229 to £393 per tonne of CO<sub>2</sub> equivalent reduced, depending on the intensity of the enterprise. Colleran (1998) outlines a number of technical options for the reduction of methane emissions per animal in the Irish dairy herd but does not discuss the costs (or cost savings) that may be involved. Finally Teagasc, the Irish Environmental Protection Agency (EPA), the Irish Department of the Environment and the Irish Department of Agriculture, Food and Rural Development have all produced numerous reports looking at issues such as feeding regimes and different farm management practices to reduce methane emissions, trends in methane emissions, climate change strategies, yearly emission to air statistics, etc. (EPA,2000; EPA2002; Department of Agriculture, Food and Rural Development, 2001; Department of the Environment, 2000; Teagasc,2001)

### 3. Greenhouse Gas Emissions In Irish Agriculture

The Common Agricultural Policy (CAP) of the European Union has operated a system of price support for over 45 years in Europe that has encouraged expansion of agricultural output to gain food self-sufficiency. Under the Common Agricultural Policy (CAP), a high level of price support for many agricultural products favoured intensive agriculture and high use of fertilisers and pesticides. This resulted in a rapid increase in the size of the national herd, the pollution of water systems and soils and damage to delicate ecosystems. The resulting high treatment costs were borne by consumers or taxpayers (Murphy and Lally, 1998). Now, under the Agenda 2000 Reforms, The National Climate Change Strategy and programmes such as The Rural Environment Protection Scheme one has, ironically, a new set of subsidies and regulations trying to right the external wrongs resulting from over production under the CAP.

**Figure 1. Relative Contribution of Different Agricultural Methane Sources**



Source: EPA (2000)

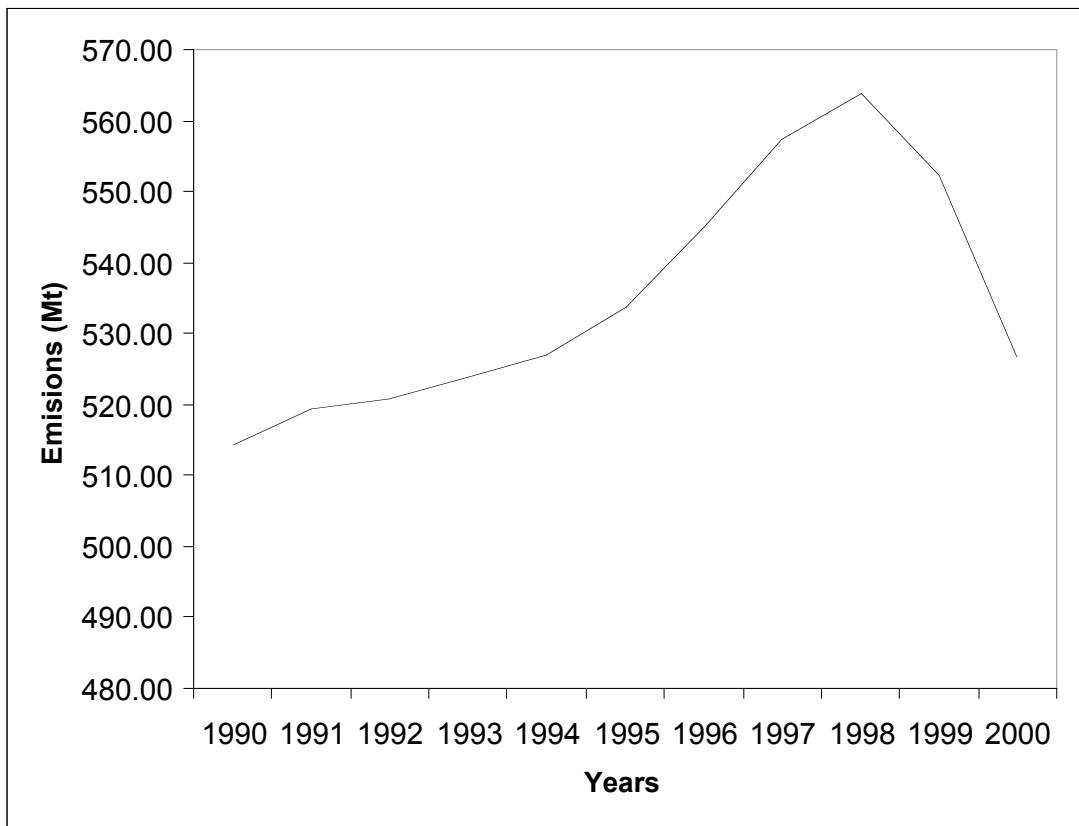
The Irish National Climate Change Strategy (NCCS) (Department of the Environment, 2000) outlines the government's objective to reduce methane emissions from the national herd by 1.2 Mt CO<sub>2</sub> equivalent. As mentioned before, this will require methane (CH<sub>4</sub>) reduction, roughly equivalent to a reduction of 10% of the national herd. Annex A of the Kyoto Protocol lists emissions from enteric fermentation (methane emissions through

microbial fermentation in digestive systems of animals), manure, rice cultivation, soil, and field burning as the main contributions of agriculture to greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC, 2001) estimates that globally, agriculture's share of total anthropogenic emissions at a global level amounts to about 50 percent of methane, about 70 percent of nitrous oxide, and about 20 percent of carbon dioxide. Agricultural emissions of greenhouse gases are very significant from an Irish perspective. Emissions from the agricultural sector accounted for 35% of all greenhouse gas emissions in 1990 (the baseline date for the Kyoto Agreement), the highest of all sectors. This is projected to fall to 26% by 2010. Methane ( $\text{CH}_4$ ) is the main greenhouse gas released in the Irish agricultural sector. In Ireland's case ruminant digestion is responsible for 51% of total emissions from agriculture, with soils and manures responsible for 35 and 10 percent of the remaining emissions from the sector respectively.

The main contributors of  $\text{CH}_4$  from ruminant animals (1990) in Ireland are cattle (87%) and sheep (13%). Figure 2 highlights the relative importance of the cattle sector in the production of methane in Irish agriculture. The NCCS predicts that agricultural emissions will increase by 3.3% during the period 1990 – 2010 with Ruminant digestion, soils and manure management increasing by 0.2%, 5.1% and 6.3% respectively.

$\text{CH}_4$  emissions from the national cattle herd constitute approximately one fifth of Ireland's total greenhouse gas emissions. Reductions in this area could go along way in fulfilling Irelands commitments as set out in the Kyoto Protocol. This is all the more relevant considering Ireland's greenhouse emissions were already more than double the Kyoto 13% growth limitation target in 2001 (EPA, 2002).

**Figure 2. Methane Emission Trend from Agriculture 1990 –2000**



Based on figures from the EPA (2002)

It should be noted however that Irish agriculture is also the main contributing sector of nitrate oxide ( $N_2O$ ), accounting for 79% of total emissions of this gas in Ireland. Even though  $N_2O$  accounts for only 4% of total greenhouse gases, the global warming potential (GWP) of this gas is 310 times that of carbon dioxide (the GWP of methane is 21 times that of  $CO_2$  ).

**Table 1. Source of Methane Emissions in Agriculture (1000 Tonnes)**

	Agriculture	A. Enteric	B. Manure
	(Total)	Fermentation	Management
1990	514.27	452.65	61.62
1991	519.46	456.95	62.51
1992	520.90	457.53	63.37
1993	523.88	459.74	64.14
1994	526.90	461.97	64.93
1995	533.67	467.60	66.07
1996	544.85	477.19	67.66
1997	557.34	487.85	69.49
1998	563.93	493.56	70.37
1999	552.19	482.93	69.26
2000	526.67	460.21	66.46

Source: EPA (2002)

The source of methane emissions in the Irish agriculture sector over the 1990s is shown in Table 1<sup>2</sup>. Appendix A shows the corresponding breakdown of methane emissions for the different animal sectors. The cattle sector in Ireland is by far the most important as regard emission levels, accounting for 87% of total methane emissions from agriculture in 2000. The value to society of methane emission reduction from the Irish livestock sector is looked at in the next section.

#### **4. Benefits and Costs of Methane Emission Reduction**

CH<sub>4</sub> emission reduction confers benefits to society by avoiding the impacts of global warming. Emission abatement in agriculture could be achieved through reduction in the size of the national herd and/or a significant change in farm management practices (Adger

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<sup>2</sup> Enteric fermentation refers to ruminant emissions of methane during the processes of digestion.

and Brown, 1994). The net worth of the abatement is the value of the benefits of a reduction in pollutants less the costs. The costs involved would be the reduction in farmer income less the saved government budgetary and consumer costs of such a reduction.

The framework of a cost-benefit analysis will be used here, to calculate the net worth to society of a reduction in the size of the national herd to a level that is consistent with the Irish government's stated 10% methane emission reduction target. The economic method of "net present value" is used (very approximately) to express the net value over time (Thomas, 1996). The NPV discounts the future at a rate that is empirically observed by economic behaviour in an economy.

$$\text{Net Present Value} = \sum_0^T \frac{(B_t - C_t)}{(1+r)^t}$$

Where:  $B_t$  = value of benefit of pollution avoided, i.e. reduced methane emissions from livestock,

$C_t$  = net value of costs of lost income less the saved government budgetary costs (direct payments),

T = time horizon ( $\infty$ )

t = time period in which costs or benefits accrue,

r = discount rate.

In section 4.2 we adjust this formula when estimating costs, as we shall see below, but our global benefit calculations are generally based on the formula, where t is commonly set to 100.

#### 4.1 Benefits

To estimate the benefits of reducing  $\text{CH}_4$  emissions, an estimate of  $\text{CH}_4$  emissions is firstly required. The gas has then to be converted, using global warming potential (GWP) factors, to calculate  $\text{CO}_2$  emission equivalents. The GWP of methane can be taken as 21 times that of  $\text{CO}_2$  or 56 times (Intergovernmental Panel on Climate Change (IPCC), 1996). The GWP of 21 is used if one believes that most of the damage from greenhouse

gas emissions is going to occur over a 100 year period. The figure of 56 is used if on the other hand one believes the resulting damages are going to be more imminent, that is over a 20-year horizon. The first estimate will be the one generally used in this paper, unless otherwise stated. The green house gas equivalent measure of methane is calculated as:

$$E_{CO2eq} = E_{CH4} \times (21)$$

Where  $E_{CO2eq}$  is total  $CO_2$  emission equivalents and  $E_{CH4}$  is gross agricultural emissions of methane. Finally, a monetary value for the future damage per unit of  $CO_2$  equivalent is used to produce a value of the benefit per head of  $CH_4$  emission reduction.

The marginal damage caused by a metric ton of carbon dioxide emissions in the near future have been estimated in a number of studies (Nordhaus, 1994; Plambeck and Hope, 1996; Tol, 1999). These studies have investigated various emission scenarios and damage and abatement functions, which rely on extrapolation from one economy across all regions of the world and have resulted in a range of cost per tonne of carbon (tC) estimates. The estimates are difficult to compare as different studies assume different climate scenarios, different assumptions about adaptation and include different impacts. They can however, according to Tol et al. (2001), still “provide insights on signs and order of magnitudes”.

All the studies in Table 2 are based on what is called the “first generation” of studies of total economic impacts as reviewed in the IPCC Second Assessment Report (1996). This report estimated the marginal damage caused by a metric ton of carbon dioxide emissions in the near future at between US\$5 – \$125 per tC. A number of studies have since reassessed the marginal damage costs of greenhouse gas emissions. The Eyre et al. (1998) study estimated the damage costs associated with increasing concentrations of greenhouse gas emissions using two different economic models, the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) and the Open Framework model.

The actual damages included in the Eyre study are reported in Appendix B. This study highlights the fact that even though emissions may result in a country such as Ireland, the

costs may be inflicted in another part of the world. Indeed, the two models in this study found that the cost for industrial countries (the countries with the majority of total emissions) are relatively modest compared to the substantial costs involved for areas such as South-East Asia and Africa – the two regions experiencing more than half the total damage costs.

**Table 2. Estimates of the Marginal Damage Costs of Carbon Dioxide Emissions (in \$/tC), using Net Present Values**

<b>Discount Rate</b>	<b>1%</b>	<b>3%</b>
<b>Plambeck and Hope (1996)</b>	<b>46</b>	<b>21</b>
<b>Eyre et al. (1998):</b>		
<b>FUND Model</b>	<b>46</b>	<b>19</b>
<b>Open Framework Model</b>	<b>44</b>	<b>20</b>
<b>Tol (1999):</b>		
<b>Best Guess</b>	<b>23</b>	<b>9</b>
<b>Equity weighted</b>	<b>60</b>	<b>26</b>

One of the values estimated by Tol (1999) uses equity weighting. This is an aggregation procedure that takes into account that a dollar is worth more to a poor person today than to a rich one. In this way more emphasis is put on the impacts in developing countries so the estimates obtained are considerably higher than the other studies in Table 2. Even Tol's own alternative "best guess" estimates for the cost of damages is less than half that of the equity weighted values.

The results obtained in the above studies and in any study relating to global warming impacts are very sensitive to the discount rate used. The rates used in these and other studies of climate change impacts range from 0 to 3 percent. This is well below what is considered to be a standard "social" discount rate (Mount, 1999). In Ireland, for example, the standard rate used is 6%. The lower the discount rate the more likely one would be led to select programs or options that have high net benefits in the more distant future.

The choice of discount rate in a cost benefit analysis for environmental assets has proven to be a very controversial subject (Field, 2000; Azar and Sterner, 1996). It is not the aim of this paper to investigate or develop the argument relating to the choice of discount rate. It must be stated however, that many analysts of environmental problems argue that lower

discount rates than usually apply should be used for appraising situations where the costs and benefits in question are a long way in the future.

In this paper we will take €50 as the present value benefits from an abatement of one ton of carbon dioxide, or the equivalent. This is near the upper range of estimates in Table 2 and so is a conservative estimate, in the sense of giving a high weight to potential damage from global warming.

## 4.2 Costs

We have decided also to be conservative in estimating net present value of costs, where this also means putting a premium on avoiding global warming. This is done by choosing a relatively low value, within the plausible bounds, for the long term costs to farmers of abatement.

Specifically, we have no way of knowing how long it will take farmers, in the long run, to re-adjust their fixed factors of production and their technological choices to the constraints imposed by abatement restrictions. Family labour, land and other fixed factors, as well as technology choices, tend to be adjusted at a slower rate than short run variables such as inputs, variable factors and outputs. Adjustment among the latter are already accounted for when we come to calculate annual costs, as we shall see below. We simply multiply this calculated annual cost by five to get a figure for the net present value of all future costs. The choice of a multiple of five means that we have assumed that fixed factors and technology are re-adjusted over a five year period (a little more actually – because of discount rates) to such an extent that all farm income losses due to abatement are restored by the end of that period.

The annual cost of the reduction of methane is the revenue lost less the variable costs not incurred<sup>3</sup>. One should also consider, when estimating short term costs, the gain to society from rebates to the FEOGA budget if activities with premia decrease because of restrictions on methane. The direct payments for the cattle sector include cattle headage, beef cow, beef premium, suckler cow premium, deseasonalisation premium,

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<sup>3</sup> For further discussion on the costs to Ireland of greenhouse gas abatement see D. Conniffe et al. (1997)

extensification premium and the Slaughter scheme. In the sheep sector, sheep headage, ewe premium and ewe supplementary measures are included. The total figure used for direct payments excludes payments under the different animal health schemes and the Rural Environment Protection Scheme. Following the MacSharry reforms and Agenda 2000, direct payments in general fell over the last number of years. The major part of price support, following the Luxembourg Agreement in 2001, is currently being phased out and the production decision process of Irish (and most EU) farmers will, from 2005 onwards, not depend on the size of their herds and “the cheque in the post” system but the return they can get at market and the net margins of the farm enterprise.

The cattle sector is by far the most important with regard to the level of methane emissions in Ireland. Total cattle numbers in 1990 was almost exactly seven million. This rose to a high of 7,779,450 in 1998 but by the end of 2000 cattle numbers had fallen back to near 1990 levels (7,232,400). If the Irish government is to follow through on its targeted reduction of methane emissions equivalent to a 10% reduction in the size of the national herd over the period 1990 – 2010 then the total reduction will have to take place from 2001 onwards, as the national herd is only back to 1990 levels since the end of 2000.

Other factors apart from herd size can also be manipulated to reduce emissions. “A balance will be maintained between direct reductions in stock numbers and investigation into other abatement measures such as feeding programmes, additives, probiotics, engineering and finishing cattle at a younger age, all of which would be a means of reducing emissions per animal” (Department of the Environment, 2000). However, most of the focus in Ireland has been on methane and herd size reduction, so that is our main focus in this paper. We also keep an eye on changes in other areas (e.g. changing level of nitrous oxide if methane levels are reduced). Most of the focus, also, is on the direct effects on the agricultural sector, although the FEOGA rebates are also reported.

A behavioural model which allows for substitution both between activities and among feeding patterns is available for the short term cost calculations. It can be used to find the cost minimising way of reaching any abatement target (where inputs, outputs and variable factors are all flexible). It can be used, through repeated simulations at different

abatement levels, to estimate marginal abatement cost curves (i.e. the marginal cost at different levels of abatement). The costs to the farming sector of abatement and the gains to the budgetary authority (the EU) can also be separated. The model we use - CAPRI (Common Agricultural Policy Regional Impact) – will now be briefly introduced. More complete descriptions can be found in Garvey and McInerney (forthcoming), Perez I., Wieck C., Britz W. (2003) and on the internet site [www.agp.uni-bonn.de/agpo/rsrch/capri/capri\\_e.htm](http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm).

## 5. The CAPRI Model Introduced

CAPRI is a spatial economic model that utilizes positive mathematical programming techniques in order to maximize net regional agricultural income subject to physical, biological, and political constraints. More than 200 EU NUTS 2 regional estimations are simultaneously carried out in the full model. Within each region, agricultural production is decomposed into 50 activities, using 35 possible inputs, and returning 60 outputs, according to definitions specified by the European Accounts for Agriculture. One disadvantage of the model, for our purposes, is that forestry is not incorporated – and any carbon sink effects are not included.

The model has two components – a supply component, where prices are taken as given, and a market component, where quantities are taken as given. An iterative process achieves equilibrium between them. The model incorporates all payment schemes and their respective ceilings, as well as set-aside obligations and production quotas. International agricultural trade, tariff rate quotas, intervention purchases, and subsidized exports are also modeled in the market component of the model. The model is a behavioural comparative static model, in the sense that farmers are assumed to maximize profits for a simulated year, but many of the parameters have been econometrically estimated and are not simply taken from the literature. It is principally in the market component that elasticities etc. are taken from the literature.

The Capri model adopts the IPCC (Intergovernmental Panel on Climate Change) methodology for measuring Greenhouse Gas Inventories, which involves utilising

emission factors that are linked to endogenous activities and technologies ex-post. The model can be used with either Tier 1 and Tier 2 IPCC definitions (IPCC(1997)). For the present simulation a validated set of Tier 2 calculations are used (Perez(forthcoming)). For Ireland, these are lower in general than the Tier 1 equivalents. In the base year of the CAPRI model (called 2001, but defined as an average of 2000, 2001 and 2002) total emissions calculated according to the Tier 2 methodology are of the order of 433,000 tons of methane. This is about 13% lower than the Tier 1 equivalent<sup>4</sup>.

The simple scenario that we model is the comparative static one of a 10% reduction methane emissions in 2001. This is carried out for Ireland, and for the two NUTS 2 regions of the country (the Border Midlands and West, and the East and South). Only the supply side of the model is used, so we assume fixed prices. The simulation finds the most cost effective way of reaching the reduction targeted, since farmers in both regions are assumed to maximize annual profits subject to the 10% methane reduction constraint. We go on construct a marginal abatement cost curve for Ireland, and the two regions. The main benefits of doing this repeated simulation are that we get a sense of the extra costs imposed by deeper emission cuts (substitution strategies are more costly the deeper the cuts) and that we can compare national and regional costs with plausible benefits for a range of emission cuts.

Before presenting the results, we briefly outline the main features of the model that are relevant for the reported simulations.

### **5.1 Feeding requirements in the model**

There are four feeding requirements functions, derived for 19 animal activities modelled in CAPRI, with 10 feeding compounds included. In the feeding model, the requirements for each animal activity are estimated depending on ingestion capacity, live-weight, days of production, and yields, which result in net energy lactation, crude protein, fibre and dry matter for each animal activity. An animal has to exactly meet energy and crude protein requirements and ingest a minimum amount of fibre and dry matter. Calibration is

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<sup>4</sup> This opens up the question of whether any actual obligatory methane reduction of 10% is in fact moot, since re-definitions on their own in agriculture achieve a 13% reduction.

ensured by including the possibility of ‘luxury feeding’ when requirements are exceeded. Fodder prices for non-tradable feeds are then estimated and included as input costs in the objective function. Similar to the IPCC, energy requirements for cattle, and sheep and goat activities are divided into maintenance, lactation, growth and pregnancy.

## **5.2 Fertiliser requirements in the model**

Crops require their nitrogen needs to be met by both mineral and organic fertiliser application. In the model this facilitates consistency between regional organic manure production by animals and consumption of mineral fertiliser. Both sources and sinks of nitrogen are identified. Nutrient export by harvested crops must be covered by either fertiliser type, although this need is somewhat reduced by biological-fixation and atmospheric deposition. Nutrient correction and availability factors ensure calibration to observed data from bio-physical equations using information on organic fertiliser use and organic fertiliser production. Different animal activities and manure management systems require different emission factors. Organic fertiliser is calculated based on output functions for each animal category, while consumption of mineral fertiliser is calculated using FAO data. The latter is decomposed into that used by individual crops by engineering functions.

The nitrogen balance is linked to the GHG model by chemical reactions of ammonia and nitrogen in soils, which release nitrous oxide. In the second part of the fertiliser model, nitrogen in organic fertiliser is allocated to crops.

Given that there are many small and geographically dispersed sources of GHG in agriculture, the direct measurement of emissions is difficult. The CAPRI model uses a ‘bottom-up’ approach for such measurements. This involves using information on emissions from laboratory experiments and incorporating relationships derived from biophysical models. Agri biophysical models identify the possible agricultural GHG sources and estimate emission factors. This information is combined with emission records from climate projection models so that consistency is ensured in the regional supply models.

In addition, CAPRI follows a multi-strategy approach in modelling global warming emissions. Agriculture emits several GHGs, two of which, methane and nitrous oxide are explicitly modelled.

### **5.3 Methane Emissions**

(See appendix for details of the coefficients used by CAPRI to calculate methane emissions)

- 1) Methane Emissions from enteric fermentation: Methanogens depend on the breed, age, activity, fodder composition and ingestion of the animals. Capri adopts the IPCC methodology for calculating CH<sub>4</sub> emissions from enteric fermentation. Gross energy intake per animal is calculated based on digestibility parameters for Western Europe from the IPCC. This conversion parameter is used to calculate gross energy intake. Animal production and regional differences are introduced through a ‘net energy’ variable, which is covered by the feeding requirement functions in the model. The fraction of gross energy converted into methane is then calculated. Therefore, annual emissions of methane from enteric fermentation for each region can be estimated. Thus, enteric fermentation coefficients per head depend on the energy needs of the animal activity, with those activities characterised by high protein intake and low nitrogen rates emitting higher levels of methane.
- 2) Methane Emissions from Manure Management: This includes the aerobic decomposition of CH<sub>4</sub> from manure management, which encapsulates the duration and type of storage, how it is applied on the field, and whether it is in solid or liquid form. There are specific conversion factors for each system and for different climates. The IPCC gives some information on manure management systems per animal type for Western Europe e.g. for anaerobic lagoons, liquid slurry, solid storage. Estimation of methane emissions from manure management is consistent with the IPCC tier-2 approach. Emissions are estimated by multiplying solid excretion by a methane conversion factor (from manure) and a conversion factor for each management system for the number of days kept in the system.

## **5.4 Nitrous Oxide Emissions**

- 1) Nitrous Oxide ( $N_2O$ ) emissions from manure management and excretion on pastures: Nitrous oxide formation in soils is mainly due to the processes of nitrification and denitrification. The amount emitted depends on systems used and the stage of the cycle. The production of  $N_2O$  requires an aerobic process like nitrification (e.g. when manure is stored in a solid state), whereas anaerobic conditions generally lead to the production of  $CH_4$  (e.g. in anaerobic lagoons or slurry tanks). Emissions of  $N_2O$  from manure management, between 0 and 3 Kg per head/year, differ across regions due to differences in manure excretion rates.  $N_2O$  from manure management is calculated by multiplying the nitrogen content in manure by an  $N_2O$  conversion factor for each system and climate by 44/28 (conversion factor for  $N_2O-N$  into  $N_2O$ ) for the level of production for each activity.  $N_2O$  from manure excretion on pastures is calculated in a similar way, substituting an  $N_2O$  conversion factor for grass and pastures for the conversion factor for system type.
- 2)  $N_2O$  from Mineral Fertiliser Application: Organic and mineral fertiliser are allocated to crops according to estimated shares. This allows for different emission coefficients depending on the type of fertiliser used. Total applied nitrogen from mineral fertiliser is estimated by calculating the total nitrogen on crops (i.e. nitrogen need of crops plus a regional over-fertilisation factor) multiplied by the fraction of mineral fertiliser to total fertiliser used.
- 3)  $N_2O$  Emissions from Nitrogen fixing crops: Nitrogen fixation is the process of converting atmospheric nitrogen used by crops. An example of this is ‘biological fixation’, when certain plants convert atmospheric nitrogen to ammonia. This additional nitrogen is also subject to nitrification, and thus  $N_2O$  emissions. In the CAPRI model, pulses generate 75% of their nitrogen by biological fixation, while ‘other fodder on arable land’ and ‘grass and grazings’ generate 10% and 5% respectively.  $N_2O$  emissions from this nitrogen fixing are calculated by multiplying the nutrient demand of crops by a conversion factor for nitrogen import from biological fixation. This is then corrected for the possibility of over-

fertilisation and multiplied by the N<sub>2</sub>O conversion factor for manure application on grass.

- 4) N<sub>2</sub>O from crop residues: Crop residues left on the field are also a source of nitrogen when they decompose, and therefore are a source of nitrous oxide. In the model, the calculation is based on IPCC methodology, given that no data on crop residues for individual activities and residue burning practices are available at a regional level. This is calculated by multiplying the fraction of the crop left on the field by the yield of the crop and by the percentage of residue in the crop. This is then adjusted for the fraction of dry matter in the residue and multiplied by the N<sub>2</sub>O emission factor for nitrogen.
- 5) Indirect N<sub>2</sub>O Emissions from Atmospheric Deposition: Some of the nitrogen losses from fertiliser are volatised as ammonia, transported off the farm and become available again through rainfall on soils. This leads to indirect N<sub>2</sub>O emissions. In calculating N<sub>2</sub>O emissions from nitrogen in ammonia losses deposited on agricultural soils, the nutrient demand of crops is firstly multiplied by a correction factor for over-fertilisation and the proportion of mineral fertiliser in total fertiliser used. This is then adjusted for nutrient losses in the application of mineral fertiliser and an N<sub>2</sub>O emission factor for ammonia losses.

The inclusion of these additional sources of nitrogen makes the model more realistic, by lowering the amount of fertiliser that is needed in certain regions.

Emissions are reported on a per hectare basis. Methane and Nitrous Oxide emissions are assumed to be equally distributed on land within a NUTS II region and a hectare average is calculated. As mentioned, CAPRI is capable of delivering a detailed analysis of production at a regional level. Thus, as Perez et al (2003) explain, given the diversity in soil types across regions, and differences in yields and production-mix, environmental impacts have the potential to vary greatly. In addition, the use of mathematical programming allows the modelling of many regions, activities, technologies, and environmental indicators. Furthermore, the explicit modelling of policy facilitates the assessment of the environmental impacts of different scenarios.

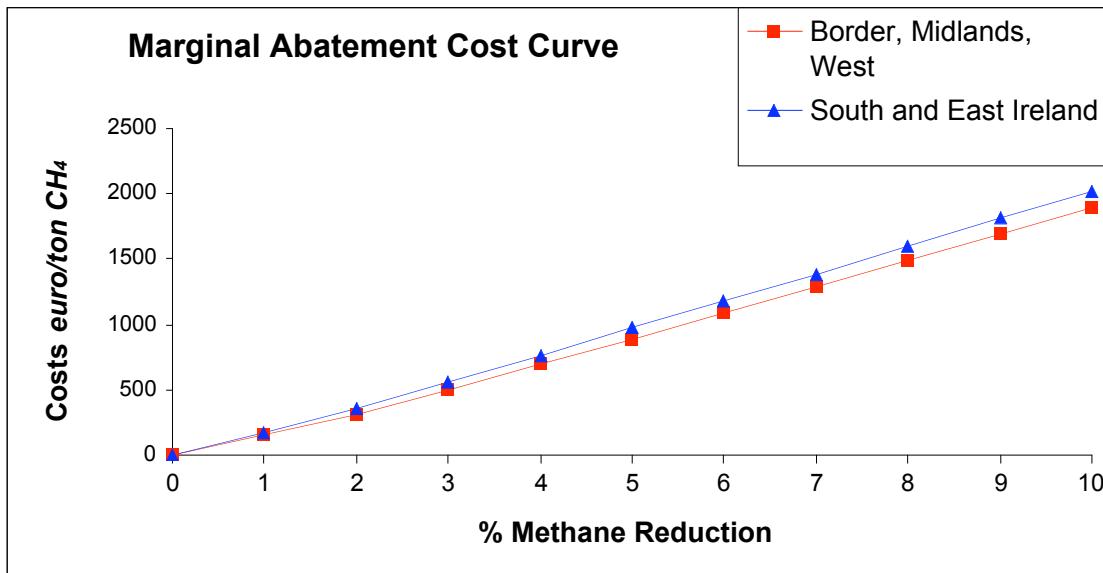
## 6. Results

In CAPRI, marginal costs for the abatement of Global Warming Emissions approximate the marginal income loss from a one tonne reduction of carbon dioxide equivalents. As described in Perez et al (2003), marginal abatement costs are estimated in CAPRI by introducing emission standards as constraints in the regional supply models and increasing the constraint iteratively. The shadow value of the constraints is equal to the marginal income loss at each unitary reduction. Reductions in the level of emissions are achieved by changes in the level, intensity, or composition of production and changes in technology. The solution returned by the model, when run under various environmental policy constraints, will be the most cost-effective means of compliance in terms of production, activity levels etc.

In order to construct marginal abatement cost curves for Ireland, the model was calibrated to 2001 data and emissions of methane were reduced on a stepwise basis up to 10%. The model was only run for Ireland (a full version of the model uses all 200 plus NUTS 2 regions of the pre-accession EU), and so the market and world-trade part of the model is not used. Thus, knock on price effects of methane reduction are not modelled (a reduction in herd sizes is likely to raise meat prices). The model results as reported in this paper come simply from the profit maximizing outcome, on the supply side only (i.e. with given prices), of the simulated 10% methane restriction in 2001. Global warming potential, as such, has not been restricted by 10% - only methane emissions – but the effects on nitrous oxide emissions of the 10% methane restriction can also be tracked. The reason for a focus on methane rather than GWP per se is that most of the policy discussion in Ireland has been on methane restrictions.

Figure 3 below plots the marginal abatement cost curve for Ireland's NUTS II regions (euro per tonne of methane) and Table 3 gives the marginal costs for each percentage of abatement in euro per tonne of carbon dioxide equivalent for Ireland and the regions.

**Figure 3: Marginal Abatement Cost Curve for Methane in Ireland ‘s NUTS II regions, 2001 (euro per tonne of Methane)**



As can be seen from the abatement curves for Ireland, linearity is a fair approximation. It is clear also that there are small inter-regional differences in the cost of compliance with environmental policy constraints. Marginal abatement costs tend to be higher in the South and East Ireland region than in the Border, Midlands, and West (BMW) region. The marginal cost for the tenth percentage reduction in methane emissions is €90.19 per ton of CO<sub>2</sub><sup>e</sup> (carbon dioxide equivalent) for the BMW region and €96.31 per ton of CO<sub>2</sub><sup>e</sup> for the South and East region. The national marginal costs for Ireland is a weighted average of the two i.e. €93.65 per ton of CO<sub>2</sub><sup>e</sup>. This is mainly due to productivity differences, whereby regions with lower productivity can meet certain abatement targets at relatively lower costs. With regard to reductions in methane emissions in particular, these are mostly achieved by a fall in the level of sheep and cattle.

As these activities are particularly dominant in the BMW region, reductions in methane emissions are relatively less costly to engineer. Production in the South and East Ireland region is more diversified, with cereal crops being particularly important. These crops require a high fertiliser input and methane restrictions would therefore be relatively more taxing on the farmer. In addition, the dairy sector is particularly strong in the South and a reduction in emission from such a profitable activity would be costly.

**Table 3: Annual Marginal Abatement Costs to the Farming Sector in Euro per ton of CO<sub>2</sub><sup>e</sup> for Ireland and NUTS 2 Irish regions for Methane Reduction, 2001**

CH <sub>4</sub> Reduction%	Ireland	Border, Mid., West	South and East
0	0	0	0
1	7.93	7.39	8.34
2	16.16	14.98	17.08
3	25.44	23.81	26.68
4	34.96	33.05	36.44
5	44.62	42.48	46.27
6	54.31	51.95	56.12
7	64.04	61.43	66.04
8	73.84	70.95	76.06
9	83.74	80.56	86.18
10	93.65	90.19	96.31

The differences within Ireland suggest that a uniform reduction policy across regions may not be optimal but perhaps, instead, that a slightly larger burden could be placed on the BMW region. It does seem clear that there is little scope for an inter-regional emission permit-trading system within Ireland, given that transactions costs would probably negate whatever marginal cost differences exist. At Member State level however, the scope is considerably wider, as marginal abatement costs in Ireland are among the lowest in the EU (see Perez et al (2003), p11). Also, within Ireland, inter-farm emissions trading is an option that may reduce marginal abatement costs nationally.

Table 4 below also presents the cumulative costs of meeting methane emission reduction targets of up to 10% for Ireland. These costs are measure by changes in the value of the objective function, which maximises agricultural income for each level of the methane constraint. The slope of the marginal abatement cost curve means that these costs rise steeply as the cuts get deeper. A 1% reduction in methane emissions reduces income by approximately €40,000 only, but a 10% reduction in methane emissions is roughly 1000 times as expensive, at least in terms of lost agricultural income (there are compensating

gains for the FEOGA budget, which will be discussed below). This increase in costs to farmers according to the size of the emissions cut is a very important consideration if a time comes when actual cuts are to be made. However, it should be noted that these costs are low, even with methane abatement of 10%. The spare grass available due to the decline in sucklers and other cattle for fattening (see Table 6 below) contributes to cheaper feed costs for these other cattle, which strongly mitigates what would otherwise be a more severe income decline.

**Table 4: Cumulative Income loss from Methane Reductions ('000s Euro)**

Methane Reduction %	Methane('000 t)	Income loss to Farming (€'000)
0	432.998	0
1	428.668	40.59
2	424.338	1450.79
3	420.008	3336.83
4	415.678	6081.79
5	411.348	9699.75
6	407.018	14197.56
7	402.688	19577.63
8	398.358	25845.51
9	394.028	33009.22
10	389.698	41074.02

The reported annual income loss values of Table 4 should be factored upwards to get a measure of perpetual or long-term losses to allow for the fact that losses are not confined to one year. In Table 5, the marginal costs of Table 3 are multiplied by five to get an approximation for the net present value of marginal abatement costs. The rationale for using a factor of five instead of the usual discount type formula has been discussed at the end of section 4.2.

**Table 5: Estimated Net Present Value of Marginal Abatement Costs to the Farming Sector and EU Budget Holders, in Euro per ton of CO<sub>2</sub><sup>e</sup> for Ireland and Irish Regions.**

CH <sub>4</sub> Reduction%	Ireland	BMW	South and East
0	0	0	0
1	39.65	36.95	41.7
2	80.8	74.9	85.4
3	127.2	119.05	133.4
4	174.8	165.25	182.2
5	223.1	212.4	231.35
6	271.55	259.75	280.6
7	320.2	307.15	330.2
8	369.2	354.75	380.3
9	418.7	402.8	430.9
10	468.25	450.95	481.55

On these estimations, and given a one-to-one exchange rate for the euro and dollar (a good approximation for the year in question), any methane abatement larger than about 1.25 % is not worth it. If the reduction in emissions is any larger, then losses in the sector outweigh global gains. The reason for this is that the per ton costs of abatement rise with higher abatement levels due to the increasing marginal cost of abatement.

Table 6 below shows the expected changes in activity levels, nationally and regionally, given a 10% reduction in methane emissions. Only animal activities are shown due to the fact that they are the main emitters of methane. It is clear that the main changes will take place in the suckler cow and sheep and goat sectors: suckler cow numbers are expected to fall between 20% and 22% and the dairy sheep and goat herd size by between 17% and 20%. In addition, the number of high-weight bulls and heifers, relatively higher emitters of methane, are expected to fall between 10% and 12%, while the size of the male and female calf-raising herds falls between 11% and 15%. There is little change in the dairy cow herd due the quota system and its profitability to the farmer.

**Table 6: Changes in Activity Levels in Response to 10% Methane Abatement, 2001**

Region	Ireland		BMW		South and East	
Activity	Base year	10% Abatement	Base year	10% Abatement	Base year	10% Abatement
Units	1000 ha or hds	1000 ha or hds	1000 ha or hds	1000 ha or hds	1000 ha or hds	1000 ha or hds
Dairy Cows high yield	584.55	593.98 1.61%	242.07	245.82 1.55%	342.48	348.17 1.66%
Dairy Cows low yield	584.54	562.52 -3.77%	242.06	233.32 -3.61%	342.47	329.2 -3.87%
Suckler Cows	1160.77	916.72 -21.02%	608.44	487.12 -19.94%	552.33	429.6 -22.22%
Heifers breeding	303.28	268 -11.63%	113.04	100.66 -10.95%	190.24	167.34 -12.04%
Heifers fattening high weight	267.96	234.52 -12.48%	109.32	96.43 -11.79%	158.64	138.09 -12.95%
Heifers fattening low weight	267.96	253.1 -5.55%	109.32	103.58 -5.25%	158.64	149.52 -5.75%
Male adult cattle high weight	468.9	418.39 -10.77%	187.56	168.42 -10.20%	281.34	249.97 -11.15%
Male adult cattle low weight	468.9	434.57 -7.32%	187.56	174.46 -6.98%	281.34	260.11 -7.55%
Raising male calves	935.18	825.74 -11.70%	361.29	321.38 -11.05%	573.89	504.36 -12.12%
Raising female Calves	840.64	719.74 -14.38%	324.21	280.12 -13.60%	516.43	439.62 -14.87%
Milk Ewes and Goat	3976.83	3245.83 -18.38%	1954.65	1622.73 -16.98%	2022.18	1623.1 -19.74%
Sheep and Goat fattening	3320.48	3050.31 -8.14%	1631.97	1504.46 -7.81%	1688.52	1545.85 -8.45%

These changes give some indication to policymakers of the types of cuts that are needed for an overall 10% methane emission reduction in agriculture. Cuts of roughly 20% of suckler cow numbers and 17% of ewes (plus the other cuts in the above table) would appear to be needed, if a 10% emission abatement were to be carried out at minimum

expense to the sector. Due to the effects of decoupling it is likely that suckler numbers and sheep numbers will decline over the coming years anyway, and so emission levels should approach the Kyoto targets of their own accord. However, if that were not to happen, it is clear that setting limits to total suckler and sheep numbers (perhaps different limits for the two regions modelled – if that were politically feasible) would be among the least cost ways for policymakers to achieve the kinds of severe emission cuts modelled in this paper.

It is important to note also that nitrous oxide levels fall as methane levels fall due to the methane restriction. Since the total carbon equivalents for nitrous oxide due to nitrous oxide are over .668 those of methane (6,076,000 tons for nitrous oxide compared to 9,093,000 tons for methane for 2001), the focus on methane reduction alone is limited.

**Table 7: Decline in Nitrous Oxide as Methane is Constrained**

Methane Reduction %	Coincidental NO2 Reduction %
0	0
1	0.4
2	0.8
3	1.3
4	2.1
5	2.9
6	3.7
7	4.5
8	5.3
9	6.1
10	7

To incorporate nitrous oxide more directly into the simulations, we have re-run the model to simulate a 10% reduction in total global warming potential, not specifically through reducing methane or nitrous oxide. Compared to the income loss in Table 4 of over €41,000,000, we find an income loss of €61,000,000 approximately, and common falls in methane, nitrous oxide and carbon dioxide (from fertilizer manufacture) of about 10% each. This means that, strictly speaking, slightly higher figures for costs could have been

used in the benefit cost comparisons of Table 5, since the costs of global emissions abatement are slightly higher than those of methane abatement only.

Finally, the main methane results of Figure 3 and Tables 3 and 4 do not take rebates of the FEOGA budget into account. They only measure costs to the farming sector. We have found that for all 10 simulations reported on in Figure 3 and Tables 3 and 4 the budget rebates are actually higher than the income losses, and for small abatements a good deal higher (proportionately). This is an extremely important result. It means all income losses to the sector could be compensated without going outside the FEOGA budget. Losses outweigh the rebates only at much higher levels of abatement than those reported here. The results of these FEOGA rebate calculations are reported in Table 8, combined – for comparison purposes – with the farm income losses from Table 4.

**Table 8: Cumulative Income loss from Methane Reductions ('000s Euro), plus Budgetary Rebates to the FEOGA Budget**

Methane Reduction %	Income loss to Farming ('000)	Budgetary Rebate (€'000) to the FEOGA Budget
0	0	0
1	40.6	8910.5
2	1450.8	17775.9
3	3336.8	26490.7
4	6081.8	35235.3
5	9699.8	43946.6
6	14197.6	52652.7
7	19577.6	61338
8	25845.5	70044.6
9	33009.2	78730.8
10	41074.0	87419.4

## 7. Conclusions

In this paper, we have compared many of the widely available estimated global benefits of abatement with the costs to Irish agriculture, as estimated by the CAPRI model. We have applied the model to Ireland only, in a simple comparative static simulation, and have assumed fixed prices, so the results have to be interpreted on that basis. We have

focused more on methane reduction than GWP reduction as a whole, because most of the discussion regarding global warming from agriculture in Ireland has focused on methane. But some results for nitrous oxide and for GWP have also been included.

The results suggest that the costs of methane abatement to the farming sector do indeed outweigh the global benefits, except in the case of very small methane abatements of around 1.25% or less. However, if one also factors in the gains to society of the FEOGA budget rebates, then all losses disappear, and in fact net financial gains occur. The fact that it is possible that all farming losses for methane reductions of the extent modelled here could be recompensed without increasing the FEOGA budget is an important consideration to bear in mind when designing methane reduction policies.

It may well be, of course, that the decoupling of the sector due to take place as a result of the Mid-Term Agreement will mean that such drastic cuts in emissions as modelled in this paper will not be needed. This is the focus of ongoing research.

## References

- Azar, C. and Sterner, T. (1996). "Discounting and Distributional Considerations in the Context of Global Warming" *Ecological Economics* 19: 169-184.
- Adams, R.M., C.C. Chang, B.A. McCarl, and J.M. Callaway. "The Role of Agriculture in Climate Change: A Preliminary Evaluation of Emission Control Strategies." In J.M. Reilly and M. Anderson, (eds.), *Economics Issue in Global Climate Change: Agriculture, Forestry, and Natural Resources*, pp. 273-287. Boulder/Colorado, Westview Press, 1992.
- Behan, J. and McQuinn, K. (2002). *Projections of greenhouse gas emissions from Irish agriculture, Outlook 2002: Medium term analysis for the agri-food sector*, Teagasc: Rural Economy Research Centre, Dublin, pp. 77-86.
- Binfield, J., Donnellan, T., Hanrahan K., Westhoff, P., and McQuinn, K. (2001). "The Outlook for Agricultural Sector in Ireland". In "Outlook 2001: Medium Term Analysis for the Agri-Food Sector" Teagasc Rural Economy Research Centre.
- Blok, K. and de Jager, D., 1994, 'Effectiveness of Non-CO<sub>2</sub> Greenhouse Gas Emission Technologies', *Environmental Monitoring and Assessment* 31: 17–40.
- Conniffe, D. J. Fitz Gerald, S. Scott, F. Shorthall (November 1997) "The Costs to Ireland of Greenhouse Gas Abatement" ESRI Policy Research Series (PRS) No.32.
- Convey, F.J. and Roberts, S. (2000). "Farming, climate and Environment in Ireland", Environmental Studies Research Series (ESRS) Working Paper 00/03, Department of Environmental Studies, University College Dublin.
- Department of Agriculture, Food and Rural Development (2001) "Annual Review and Outlook for Agriculture, Food and Rural Development" Johnstown Castle, Wexford, Ireland.

Department of the Environment (2000). “The National Climate Change Strategy (NCCS)” Department of the Environment, Custom House, Dublin.

EEA (European Environment Agency) (2000) “Environment in the European Union at the Turn of the Century – Offprint: Greenhouse Gases and Climate Change” Office for Official Publications of the European Communities, Luxembourg.

EPA (Environmental Protection Agency) (2000) “Emissions To Air 1990-1998 Estimation Methods, Trends and Challenges” Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

EPA (Environmental Protection Agency) (2002) “Environment in Focus 2002 – Key Environmental Indicators” Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Fankhauser, S. 1995, *Valuing Climate Change – The Economics of the Greenhouse*, EarthScan, London.

Field, B. (2000). *Natural Resource Economics*. McGraw-Hill Publishers.

Fitz Gerald, J; Hore, J; Kearney, I., (2002) “A Model for Forecasting Energy Demand and Greenhouse Gas Emissions in Ireland”, ESRI Working Papers No. 146 ESRI Dublin.

Garvey, E and McInerney, N. (forthcoming). *Quantifying the Effects of CAP Reform on Agriculture in Ireland’s NUTS \_ Regions*. Department of Economics, NUI Galway.

Godal, O. and Fuglestvedt, J.: 2002, ‘Testing 100-Year Global Warming Potentials: Impacts on Compliance Costs and Abatement Profile’, *Clim. Change* 52: 93–127.

Hammitt, J. K., Jain, A. K., Adams J. L., and Wuebbles, D. J.: 1996, ‘A Welfare-Based Index for Assessing Environmental Effects of Greenhouse-Gas Emissions’, *Nature* 381: 301–303.

Hayhoe, K., Jain, A., Pitcher, H., MacCracken, C., Gibbs, M., Wuebbles, D., Harvey, R., and Kruger, D., 1999, 'Costs of Multi-greenhouse Gas Reduction Targets for the U.S.A.', *Science* 286: 905–906.

Hourcade, J.-C., Halsneas, K., Jaccard, M., Montgomery, W. D., Richels, R. G., Robinson, J., Shukla, P. R., and Sturm, P.: 1996b, 'A Review of Mitigation Cost Studies', in J. P. Bruce, H. Lee, and E. F. Haites (eds.), *Climate Change 1995: Economic and Social Dimensions – Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 297–366.

Hogan, K. B. (ed.): 1993, Options for Reducing Methane Emissions Internationally – Volume I: Technological Options for Reducing Methane Emissions, EPA 430-R-93-006, U.S. Environmental Protection Agency, Washington, D.C.

IPCC (Intergovernmental Panel on Climate Change), (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, IPCC National Greenhouse Gas Inventories Programme.

<http://www.ipcc-nngip.iges.or.jp/public/gl/guidelin/ch4ref1.pdf>

IPCC (Intergovernmental Panel on Climate Change), (2001). Climate Change 2001: Mitigation - Contribution of Working Group III to the IPCC Third Assessment Report. World Meteorological Organization, UNEP. Cambridge University Press.

Kruger, D., Dastin-Van Rijn, M., Harvey, R., and Gibbs, M. J. (ed.): 1998, Costs of Reducing Methane Emissions in the United States, Environmental Policy Agency, Washington, D.C.

McCoy, D and Scott, S (eds.), Averous, C; Convery, F; Eakins, J; FitzGerald, J; Hore, J; Pearce, D; Von Meyer (2001),"Green and Bear It? Market Based Policies for Ireland's Environment" Proceedings of a Conference held on 10th May 2001, ESRI No. 166

McQuinn, K. and Binfield, J. (2002). "Estimating the Marginal Cost to Irish Agriculture of Reductions in Greenhouse Gases" Rural Economy Research Centre Working paper, Teagasc, Dublin.

Perez I., Wieck C., Britz W. (2003): *Modelling of passive environmental indicators for the European Agriculture: the role of marginal abatement costs*, 12th Annual Conference of the EAERE, Bilbao (Spain), June 28-30.

[http://www.agp.uni-bonn.de/agpo/staff/perez/EAERE\\_paper.doc](http://www.agp.uni-bonn.de/agpo/staff/perez/EAERE_paper.doc)

Perez, I. (Forthcoming). *Greenhouse Gases: Inventories, Abatement Costs and Markets for Emission Permits in European Agriculture – A Modelling Approach*. Phd Thesis. Hohen Landwirtschaftlichen Fakultät der Rheinischen Friedrich-Wilhelms-Universität zu Bonn

Reilly, J. M. and Richards, K. R.: 1993, 'Climate Change Damage and the Trace Gas Index Issue', *Environmental Resource Economics*. 3: 41–61.

Schimel, D., Alves, D., Enting, I., Heimann, M., Joos, F., Raynaud, M., Derwent, R., Ehhalt, D., Fraser, P., Sanhueza, E., Zhou, X., Jonas, P., Charlson, R., Rodhe, H., Sadasivan, S., Shine, K. P., Fouquart, Y., Ramaswamy, V., Solomon, S., Srinivasan, J., Albritton, D. L., Isaksen, I., Lal, M., and Wuebbles, D. J.: 1996, 'Radiative Forcing of Climate Change', in J. T. Houghton, L. G. Meiro Filho, B. A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.), *Climate Change 1995: The Science of Climate Change – Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Teagasc (2001). 2001. "Outlook 2001: Medium Term Analysis for the Agri-Food Sector" Teagasc Rural Economy Research Centre.

Tol, R. S. J.: 1999e, 'The Marginal Costs of Greenhouse Gas Emissions', *Energy J.* 20: 61–81.

Tol, R. S. J.: 2001b, 'Equitable Cost-Benefit Analysis of Climate Change', *Ecological Economics* 36: 71–85.

Tol, R., Heintz, R., and Lammers, P. (2003). "Methane Emission Reduction: An Application of FUND" *Climatic Change* 57: 71–98.

UNFCCC (United Nations Framework Convention on Climate Change) (1997) "Kyoto Protocol to the United Nations Framework Convention on Climate Change" CP/1997/L.7/Add. 1, December 1997.

Watson, R. T., Zinyowera, M. C., and Moss, R. H. (eds.): 1996, Climate Change 1995: Impacts, Adaptation, and Mitigation of Climate Change – Scientific-Technical Analysis – Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge

## Appendix

### CH4 Output of Animals (kg per animal and year) as per Tier-1 IPCC 1997

<b>High Yielding Dairy Cows</b>	<b>100</b>
<b>Low Yielding Dairy Cows</b>	<b>100</b>
<b>Suckler Cows</b>	<b>100</b>
<b>Female Calves for Raising</b>	<b>48</b>
<b>Male Calves for Raising</b>	<b>48</b>
<b>Female Calves for Fattening</b>	<b>48</b>
<b>Male Calves for Fattening</b>	<b>48</b>
<b>High Weight Heifers</b>	<b>48</b>
<b>Low Weight Heifers</b>	<b>48</b>
<b>Heifers for Raising</b>	<b>48</b>
<b>Low Weight Bulls</b>	<b>48</b>
<b>High Weight Bulls</b>	<b>48</b>
<b>Breeding Pigs</b>	<b>1.5</b>
<b>Pigs for Fattening</b>	<b>1.5</b>
<b>Sheep and goats for Milk</b>	<b>8</b>
<b>Sheep and Goats for Fattening</b>	<b>8</b>
<b>Other Animals</b>	<b>15</b>

### Conversion factor of MJ energy into kg of methane - Tier 2 IPCC 2000

<b>Activity</b>	<b>Factor</b>
<b>High Yielding Dairy Cows</b>	<b>0.055</b>
<b>Low Yielding Dairy Cows</b>	<b>0.055</b>
<b>Suckler Cows</b>	<b>0.055</b>
<b>Female Calves for Raising</b>	<b>0.055</b>
<b>Male Calves for Raising</b>	<b>0.055</b>
<b>Female Calves for Fattening</b>	<b>0.055</b>
<b>Male Calves for Fattening</b>	<b>0.055</b>
<b>High Weight Heifers</b>	<b>0.055</b>
<b>Low Weight Heifers</b>	<b>0.055</b>
<b>Heifers for Raising</b>	<b>0.055</b>
<b>Low Weight Bulls</b>	<b>0.055</b>
<b>High Weight Bulls</b>	<b>0.055</b>

### Digestibility default percentage - Tier 2 IPCC 2000

<b>Activity</b>	<b>%</b>
<b>High Yielding Dairy Cows</b>	<b>60</b>
<b>Low Yielding Dairy Cows</b>	<b>60</b>
<b>Suckler Cows</b>	<b>60</b>
<b>Female Calves for Raising</b>	<b>60</b>
<b>Male Calves for Raising</b>	<b>60</b>
<b>Female Calves for Fattening</b>	<b>60</b>
<b>Male Calves for Fattening</b>	<b>60</b>
<b>High Weight Heifers</b>	<b>60</b>
<b>Low Weight Heifers</b>	<b>60</b>
<b>Heifers for Raising</b>	<b>60</b>
<b>Low Weight Bulls</b>	<b>60</b>
<b>High Weight Bulls</b>	<b>60</b>
<b>Breeding Pigs</b>	<b>75</b>
<b>Pigs for Fattening</b>	<b>75</b>

### Tier1 manure management coefficients

<b>Activity</b>	<b>Cool</b>	<b>Temperate</b>	<b>Warm</b>
<b>High Yielding Dairy Cows</b>	<b>14</b>	<b>44</b>	<b>81</b>
<b>Low Yielding Dairy Cows</b>	<b>14</b>	<b>44</b>	<b>81</b>
<b>Suckler Cows</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Female Calves for Raising</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Male Calves for Raising</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Female Calves for Fattening</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Male Calves for Fattening</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>High Weight Heifers</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Low Weight Heifers</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Heifers for Raising</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Low Weight Bulls</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>High Weight Bulls</b>	<b>6</b>	<b>20</b>	<b>38</b>
<b>Breeding Pigs</b>	<b>3</b>	<b>10</b>	<b>19</b>
<b>Pigs for Fattening</b>	<b>3</b>	<b>10</b>	<b>19</b>

**Maximum CH<sub>4</sub> producing capacity in % of the manure (kg from kg) - Tier 2 IPCC 1997**

<b>Activity</b>	<b>%</b>
<b>High Yielding Dairy Cows</b>	<b>0.24</b>
<b>Low Yielding Dairy Cows</b>	<b>0.24</b>
<b>Suckler Cows</b>	<b>0.17</b>
<b>Female Calves for Raising</b>	<b>0.17</b>
<b>Male Calves for Raising</b>	<b>0.17</b>
<b>Female Calves for Fattening</b>	<b>0.17</b>
<b>Male Calves for Fattening</b>	<b>0.17</b>
<b>High Weight Heifers</b>	<b>0.17</b>
<b>Low Weight Heifers</b>	<b>0.17</b>
<b>Heifers for Raising</b>	<b>0.17</b>
<b>Low Weight Bulls</b>	<b>0.17</b>
<b>High Weight Bulls</b>	<b>0.17</b>
<b>Breeding Pigs</b>	<b>0.45</b>
<b>Pigs for Fattening</b>	<b>0.45</b>