
# An Illustration of the Potential Impacts and Uncertainties of an Agricultural 'Carbon Tax' on Irish Dairy Farms

*J. Lynch;*

*Teagasc, Rural Economy and Developmenty, Ireland*

*Corresponding author email: johnmichaellynch@gmail.com*

***Abstract:***

*A tax on agricultural greenhouse gas (GHG) emissions has been suggested as a potential means of reducing the GHG emissions associated with agriculture and improving the emissions intensity of production. One of several difficulties in implementing such a tax is the potential uncertainty in emissions estimates. This paper explores this topic using Irish dairy farm production and economic data from the 2015 Teagasc National Farm Survey. On-farm agricultural emissions were estimated by applying the National Inventory Report methodologies at farm level, and the uncertainties in total emissions and emissions per unit of milk produced were demonstrated using a Monte Carlo Simulation approach. The average GHG emissions footprint per kg fat and protein corrected milk (FPCM) was 1.07 kg CO2e with a relatively small uncertainty range of ± 2.59 %. If taxed at a rate of €20 per tonne of CO2e, a typical farm would have to pay €7141 (± 2.25 %), which could have a significant impact on farm incomes, but is not strongly affected by emissions uncertainties. Therefore, although there would remain a number of difficulties in designing an agricultural emissions tax, the level of uncertainty in emissions does not appear to be a significant barrier in this example.*

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**JEL Codes:** Q54, Q58

#2121

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A tax on agricultural greenhouse gas (GHG) emissions has been suggested as a potential means of reducing the GHG emissions associated with agriculture and improving the emissions intensity of production. One of several difficulties in implementing such a tax is the potential uncertainty in emissions estimates. This paper explores this topic using Irish dairy farm production and economic data from the 2015 Teagasc National Farm Survey. On-farm agricultural emissions were estimated by applying the National Inventory Report methodologies at farm level, and the uncertainties in total emissions and emissions per unit of milk produced were demonstrated using a Monte Carlo Simulation approach. The average GHG emissions footprint per kg fat and protein corrected milk (FPCM) was 1.07 kg $CO_2$e with a relatively small uncertainty range of ± 2.59 %. If taxed at a rate of €20 per tonne of $CO_2$e, a typical farm would have to pay €7141 (± 2.25 %), which could have a significant impact on farm incomes, but is not strongly affected by emissions uncertainties. Therefore, although there would remain a number of difficulties in designing an agricultural emissions tax, the level of uncertainty in emissions does not appear to be a significant barrier in this example.

## Introduction

Greenhouse gas (GHG) emissions are recognised as a significant negative impact associated with agricultural production. The global food system has been estimated as producing 16,900 million tonnes of carbon dioxide equivalent ($CO_2$e), almost 30% of total emissions in 2008 (Vermeulen et al., 2012), although figures vary depending on methodology and system boundaries, as well as underlying uncertainties. Consequently, agriculture is under pressure to reduce its associated GHG emissions.

In Ireland, agricultural GHG emissions have received particular attention in recent years. Emissions intensive ruminant livestock systems, particularly cattle, dominate Irish agriculture. As a result of this, and the size of the agricultural industry as part of Ireland's national economy, Irish agriculture is responsible for an unusually large proportion of the country's total emissions compared to other European Union Member States (Lynch et al., 2016), responsible for 32.1% of national emissions in 2015 (Duffy et al., 2017). The Irish agricultural sector is projected to grow, and the Irish government and agri-food sector have in place an ambitious growth strategy, FoodWise 2025 (DAFM, 2015), aiming to develop rural employment and increase agri-food exports. This strategy document emphasises the sustainable image of typical Irish agricultural production systems, and Irish produce has been demonstrated to compare favourably on per product comparisons, with, for example, the joint lowest carbon footprint for milk and the fifth lowest carbon footprint for beef in Europe (Leip et al., 2010). Failing to take action on agricultural GHG emissions may undermine this image of sustainability, and concerns have been raised about the potential environmental impact of the agricultural growth strategy (Wall et al., 2016).

The best means of reducing or improving efficiency of agricultural GHG emissions remains contested. Ireland has a unique, nationwide agricultural sustainability programme, 'Origin Green' (Bord Bia, 2017), a marketing initiative which estimates the greenhouse gas emissions of farms participating in its Quality Assurance scheme and suggests potential financial and emissions efficiency improvements through an associated decision support tool, the Teagasc – Bord Bia Carbon Navigator (Murphy et al., 2013). However, it has been debated whether this approach to increased emissions efficiency will be able to bring about the emissions reductions necessary for Ireland to meet its EU policy commitments and make a sufficient contribution to wider efforts to minimise the effects of anthropogenic climate change.

A tax on agricultural GHG emissions (or 'carbon tax') was recently recommended by the Irish Citizens' Assembly as a means of bringing about a greater reduction in agricultural emissions (Hubert, 2017). The suggestion of a tax on agricultural emissions has proved highly controversial, and were it adopted, Ireland would be the first and only country to do so. Concerns have been raised over whether an agricultural carbon tax would achieve the desired emissions reduction, or result in unintended consequences such carbon leakage: displacing production to other countries with less emissions efficient agriculture (Hogan, 2017). Even if these objections were overcome, there would be a number of practical difficulties in designing an appropriate agricultural emissions tax.

One of these potential difficulties in implementing an agricultural emissions tax is uncertainty in emissions estimates. It is not feasible to directly measure emissions, and so they are estimated by applying emissions factors to relevant activity levels associated with GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) provides standard emissions factors (tier 1) and describes how countries can improve the accuracy and specificity of significant emissions sources by using verified, nationally specific emissions factors (tier 2) or more detailed modelling approaches (tier 3). Whichever approach is used, there will always be an element of uncertainty in emissions factors, which can be particularly pronounced in agriculture, as they arise from complex and variable biological processes. Farm- or food product-level emissions are a combination of a number of individual agricultural emissions (and non-agricultural emissions such as tractor fuel use or energy used in the manufacture of inputs, depending on system boundaries), and cumulatively the resulting uncertainty may be considerable. If the uncertainty in emissions is very large, establishing an appropriate level of emissions taxation for specific agents or activities could prove challenging and contentious.

This paper explores this issue by providing an illustration of the potential range of emissions estimates and hence emissions taxation for Irish dairy farms in 2015. Emissions are estimated based on the Irish National Inventory Report methodology, with a Monte Carlo approach to estimate associate uncertainties.

## Methods

### *Farm data*

Farm data were provided by the 2015 Teagasc National Farm Survey (NFS). The NFS annually collects farm structural and financial data for a sample of approximately 900 Irish farms, and represents Ireland's submission to the European Union Farm Accountancy Data Network (FADN, a harmonised database of European farm micro-economic data, which all EU Member States are required to contribute to). Relevant farm inputs and outputs, management and financial data (described below for the relevant methodologies) were extracted for 314 dairy farms (defined as farms where the two thirds or greater of gross output was from a dairy enterprise) that fulfilled data requirements for modelling.

### *Emissions modelling and uncertainty*

Farm emissions were estimated based on the methodologies described in the 2017 Irish National Inventory Report (Duffy et al., 2017). Although more detailed farm-level GHG estimations are available in Ireland, including from NFS data (O'Brien et al., 2015), the data required for higher level estimates are only available for farms in relevant data collection programmes (such as Bord Bia Origin Green Quality Assurance or the NFS itself), and therefore would not be available for all farms, as would be required for a national agricultural emissions tax. Furthermore, demonstrating the approach based on a National Inventory Report ensures that the methodology is transparent, and can be readily applied to other countries.

Emissions factors as described in the National Inventory Report were replied to relevant individual on-farm agricultural activity levels (table 1). The system boundary was set at the farm gate to ensure emissions were all incurred in Ireland (i.e. not including, for example, embedded emissions from imported animals feeds) and therefore relevant to national emissions inventories and reductions commitments. Only agricultural emissions (i.e. not emissions resulting from on-farm energy use) were included to focus exclusively on a potential agricultural emissions tax. A Monte Carlo Simulation approach was used whereby emissions estimates were generated 8,000 times for each farm, each simulation sampling a single value for each emissions factor from a probability distribution function based on the emission factors and their uncertainties as reported in the National Inventory Report (Duffy et al., 2017) and/or the IPCC guidelines for calculating agricultural emissions (IPCC, 2006a). Where uncertainties are based on IPCC recommendations that only provide a typical value and upper and lower limits, as for example in the case of typical direct fertiliser nitrous oxide ($N_2O$) emissions (fig. 1a), triangular distributions were used (following Karimi-Zindashty et al., 2012). Where uncertainties were reported as percentage deviation from the typical value, the probability distribution function was considered as following a normal distribution, with the reported percentage uncertainty equating to the 2.5$^{th}$ and 97.5$^{th}$ percentile (e.g. fig. 1b) following the 2006 IPCC guidelines basis for uncertainty analysis

(IPCC, 2006b). It should be noted that although the National Inventory Report Annex 2 states that there is an uncertainty of 17% associated with enteric fermentation, it is explained in the uncertainty evaluation that the Irish tier 2 methods for cattle enteric fermentation are considered to result in an uncertainty of 15%. It is assumed that the 17% is due to other livestock categories having greater uncertainty, so 15% was used for cattle in this study. All normally distributed probability distribution functions were truncated at zero. The emissions factors, relevant activity levels, probability distribution functions and their parameters are described in table 1. No error was modelled in activity levels.

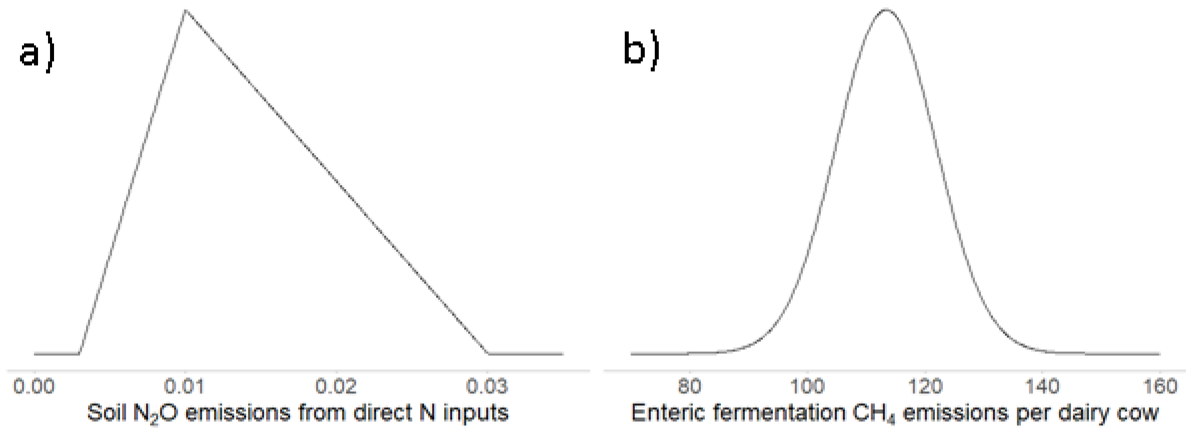


Fig. 1. Examples of probability distribution functions for emissions factors illustrating
a) the triangular distribution for direct soil N2O emissions and
b) the normal distribution for dairy cow enteric fermentation methane emissions

Only emissions resulting from dairy production were considered for this analysis. Where activity levels may have ultimately contributed to other enterprises (e.g. fertiliser applied to grazing areas that may also be used by other livestock), emissions were allocated to dairy based on the proportion of livestock units. A proportion of dairy emissions were economically re-allocated to beef production (hence removed from this analysis), based on the value of milk output relative to sales of animals and transfers to beef herds (including within the same farm). Although in practice an agricultural emissions tax would likely have to apply to all forms of production, this approach was used in this study in order to illustrate results with a unified metric (milk) while ensuring that farms could reliably be compared across different levels of specialisation.

Emissions were expressed per unit of milk output to provide a measure of emissions efficiency. Farm milk output was measured as fat and protein corrected (FPCM) standardised compared to 4% fat and 3.3 protein in order to control for difference in milk solids constituents.

Table 1. Emission factors and probability distribution function parameters as applied to relevant activity levels in order to model on-farm agricultural greenhouse gas emissions. For normal distributions the upper and lower bounds are modelled as the 2.5$^{th}$ and 97.5$^{th}$ percentile.

| Emission Factor | Activity | Emission Factor | | | |
|---|---|---|---|---|---|
| | | Modal | Lower | Upper | Distribution |
| Enteric Fermentation $CH_4$ from dairy cows – milking | No. lactating dairy cows | 113.4 | 96.39 | 130.41 | Normal |
| Enteric Fermentation $CH_4$ from dairy cows – dry | No. dry dairy cows | 50.2 | 42.67 | 57.73 | Normal |
| Enteric Fermentation $CH_4$ from dairy bulls | No. dairy bulls | 81.5 | 69.28 | 93.73 | Normal |
| Enteric Fermentation $CH_4$ from dairy calves | No. dairy calves | 27.7 | 23.55 | 31.86 | Normal |
| Manure Management $CH_4$ from dairy cows – milking | No. lactating dairy cows | 10.3 | 8.76 | 11.85 | Normal |
| Manure Management $CH_4$ from dairy cows – dry | No. dry dairy cows | 3.8 | 3.23 | 4.37 | Normal |
| Manure Management $CH_4$ from dairy bulls | No. dairy bulls | 8.4 | 7.14 | 9.66 | Normal |
| Manure Management $CH_4$ from dairy calves | No. dairy calves | 3.8 | 3.23 | 4.37 | Normal |
| Direct $N_2O$ emissions from liquid manure management | Excreta N[1] – liquid storage | 0.002 | 0.001 | 0.004 | Triangular[2] |
| Direct $N_2O$ emissions from solid manure management | Excreta N[1] – solid storage | 0.01 | 0.005 | 0.02 | Triangular[2] |
| $N_2O$ emissions from atmospheric deposition of N compounds (e.g. $NH_3$) | Volatilised N from excreta, fertilisers, etc. | 0.01 | 0.002 | 0.05 | Triangular |
| Soil $N_2O$ emissions from direct N inputs (e.g. fertiliser) | Fertiliser N (synthetic and animal manures) | 0.01 | 0.003 | 0.03 | Triangular |
| Soil $N_2O$ emissions from pasture cattle excretion | N excreted while grazing | 0.02 | 0.007 | 0.06 | Triangular |
| $N_2O$ emissions from leaching of N inputs | Total N input on agricultural soils | 0.0075 | 0.0005 | 0.025 | Triangular |
| Lime $CO_2$ emissions | Lime applied | 0.12 | 0.06 | 0.12 | Triangular[3] |
| Urea $CO_2$ emissions | Urea applied | 0.2 | 0.1 | 0.2 | Triangular[3] |

[1] N = nitrogen; only for excreta while housed, pasture excretion contributes as an N input for agricultural soil $N_2O$ emissions

[2] Following description of 'factor of 2' uncertainty range in IPCC (2006a)

[3] Lime and Urea emission factors have upper limit set at the modal value as this represents the maximum possible emissions factor where all carbon is lost as $CO_2$

***Farm economic performance and emissions tax***

Dairy enterprise gross margin, expressed per kg FPCM, was used as a measure of farm financial performance. A hypothetical GHG emissions tax was assumed at a rate of €20 per tonne $CO_2$ equivalent emitted, following the current Irish carbon tax rate on solid fuels (Office of the Revenue Commissioners, 2017) and deducted from gross margin to illustrate the potential impact of an emissions tax. This was applied to dairy emissions as estimated above, using a global warming potential (GWP) of 298 $CO_2$e for nitrous oxide ($N_2O$) and 25 $CO_2$e for methane ($CH_4$). These values were used rather than more recent GWPs (310 for $N_2O$ and 21 for $CH_4$) for consistency with the National Inventory Report.

***Analysis***

Farm-level results were scaled according to their NFS weighting value, which represents the number of farms nationally of similar size and mode of production to each survey farm. The distribution of weighted mean GHG emissions footprints per kg FPCM resulting from Monte Carlo Simulation of emission factor uncertainty are illustrated in order to demonstrate the potential uncertainties. Similar distributions of weighted mean results were obtained for the potential total dairy emissions tax per farm, and the impact of such a tax on the dairy gross margin per kg FPCM. For all Monte Carlo Simulation results, the uncertainty range was expressed as the 95% confidence intervals as a proportion of the mean.

All modelling and analysis was performed in R (R core team, 2017). Distribution sampling for Monte Carlo Simulation was performed using the packages 'triangle' (Carnell, 2017) and 'truncnorm' (Trautmann et al., 2014) for triangular and truncated normal distributions respectively.

**Results**

Typical farm dairy agricultural emissions were 1.07 (± 2.59 %) kg $CO_2$e per kg FPCM (fig. 2). Despite the large number of uncertainties modelled, the final aggregate uncertainty range was relatively small. The largest proportion of emissions, emissions from enteric fermentation, were sampled from a normal distribution with a relatively small standard deviation due to the tier 2 methodology employed in Ireland, countering the fairly large uncertainties in other emissions factors modelled as triangular distributions for smaller emissions categories. The use of even more detailed farm-level emissions modelling would be able to reduce uncertainties even more. It should be noted that only emissions factors uncertainties were modelled in this analysis, and some other uncertainties in contributing calculations, such as the implied nitrogen contents of animal excreta and the proportion of nitrogen volatilised or leached, would also have an impact. Further work could perform sensitivity analyses, comparing the impact of uncertainties in individual emissions factors to confirm which were most important, and direct further research and/or standardise methods appropriately.

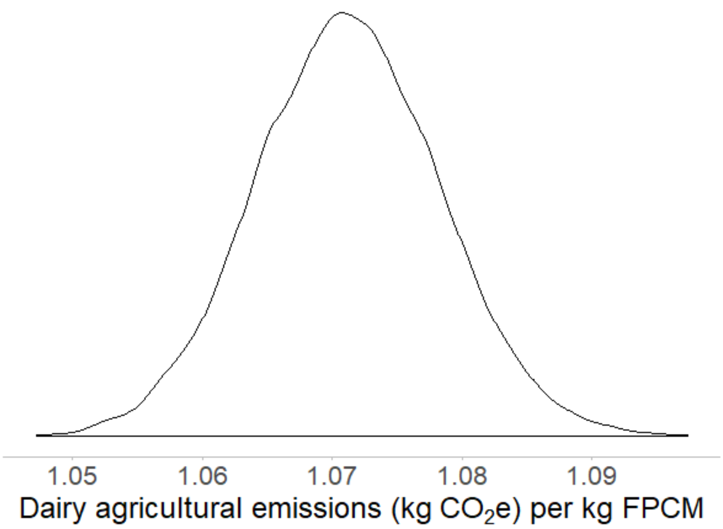


Fig. 2. Distribution of average agricultural greenhouse gas footprints (kg $CO_2$e) per kg FPCM (fat and protein corrected milk) for Irish dairy farms in 2015 following Monte Carlo Simulation of uncertainties in relevant emission factors

Typical dairy enterprise agricultural emissions were estimated at 360 (± 2.25 %) tonnes $CO_2$e per annum, corresponding to a €7141 emissions tax per farm under a €20 per tonne $CO_2$e tax rate. The suggested impact of such a tax would be to reduce gross margin per kg FPCM from €0.21 to €0.19, with little impact resulting from emissions uncertainties at this level (± 0.29 %).

**Discussion**

The cumulative impact of the uncertainties modelled in this study had relatively little effect on total emissions footprint, especially when followed through to a potential impact of an emissions tax on profitability per milk output. It is important to note, however, that not all relevant greenhouse gas processes were modelled here. In addition to the uncertainties in additional components of emissions estimation described above, there was no consideration of potential carbon sequestration. Grasslands sequester significant quantities of $CO_2$ (Fornara et al., 2011), which may be have been underestimated in previous approaches (Feng et al., 2013). A comprehensive GHG emissions tax would not only penalise emitters, but have offsets or financial rewards for sequestration. At present, however, there is no universally accepted approach to estimating sequestration, despite the significant implications for dairy emissions footprints (O'Brien et al., 2014). Incorporating soil organic carbon sequestration in emissions profiles (and hence potential taxes) would likely provoke strong (and sometimes opposing) views from a range of stakeholders, and so would require careful consideration building on the latest scientific research, accepted methodologies, including uncertainty analyses.

Although the relatively small effect of uncertainties on an emissions tax demonstrated here removed one potential barrier to its implementation, the impact and potential success of such a tax remains contested. It has been argued that while incentive based (e.g. emissions taxes) and preference based (e.g. demand management) approaches can demonstrate similar agricultural emissions reductions, a taxation based policy can result in wider negative consequences such as increased food prices and carbon leakage (Stevanović et al. 2017), and any policy options will interact with the effects of the Common Agricultural Policy (Grosjean et al. 2018). Currently, the Irish government has signalled that it does not plan to implement an agricultural emissions tax (Hogan, 2017) and such a tax would be a significant shift in the direction of global agricultural policies. Despite this, analyses such as presented in this paper can provide a valuable practical assessment of some of the issues surrounding emissions taxes, and provide important context to illustrate and inform the debate.

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