# Comparing economic performance with greenhouse gas emissions and nitrogen surplus on Irish Farms

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**Abstract**

The need to reduce the environmental footprint of agricultural production is widely recognised. At the same time, agricultural production must be sufficient to feed the expanding human population. It has been argued that this production can be achieved through sustainable intensification, with efficient intensive farms optimal for both environmental and economic performance. This paper explores this concept by comparing farm financial performance (gross margins per hectare and family farm income per labour unit) with two key environmental metrics, agricultural greenhouse gas emissions and nitrogen surpluses, on Irish farms from the 2015 Teagasc National Farm Survey. Overall, farms with better economic performance tend to have lower emissions per unit agricultural output, and obtain more agricultural output per kg surplus nitrogen applied. However, the intensive production on these economically better performing farms is also associated with greater emissions and nitrogen surpluses per hectare farmed. These results are discussed in the context of current debate surrounding agricultural policy in Ireland, where ambitions to increase agricultural production will be challenged to meet environmental targets, and in relation to wider debates around the best path for sustainable agricultural production.

**Keywords** Agricultural Production, Environmental Impacts, Irish Agriculture, Sustainable Intensification, Policy

**JEL code** **Q100**, Agriculture: General; **Q580**, Environmental Economics: Government Policy

## Introduction

Providing sufficient agricultural production to feed the growing human population poses a number of significant challenges, including the need to reduce the negative environmental impacts associated with agricultural systems(Godfray *et al.*, 2010). Much debate in this context has centred around the concept of 'sustainable intensification', suggesting that through technology adoption and appropriate management, agricultural systems can be managed more intensively in order to increase production and at the same time minimise negative impacts, for example reducing greenhouse gas emissions per unit agricultural output (Burney *et al.*, 2010) or reducing the extent of nitrogen fertilisation required (Tilman *et al.*, 2011). However, debate continues regarding the justifications for and feasibility of sustainable intensification, and whether it is the appropriate response to these agri- environmental challenges (Godfray, 2015).

Cotemporary agriculture in Ireland provides a timely means to explore some of the issues raised in relation to sustainable intensification. The Department of Agriculture, Food and the Marine has published ambitious strategy documents over the past decade: Food Harvest 2020 (DAFM [Department of Agriculture Fisheries and Food], 2010) and Food Wise 2025 (DAFM [Department of Agriculture Fisheries and Food], 2015) These reports have significant growth targets for the value of the agri-food industry, but also place an emphasis on agricultural sustainability. The sustainability of Irish production systems is an important component of international marketing initiatives, such as the Bord Bia Origin Green programme (Bord Bia, 2016). However, it has been highlighted that the level of agricultural production envisioned under these strategy documents will pose environmental challenges (EPA [Environmental Protection Agency], 2016b).

Agricultural greenhouse gas (GHG) emissions and nitrogen losses are currently receiving particular attention in the context of Irish agricultural production. Ruminant based production systems, and particularly cattle, are especially predominant in Ireland, and consequently agriculture contributes an unusually high proportion of national greenhouse gas emissions, responsible for 32% of total emissions (Duffy *et al.*, 2016), or 47% of non emissions trading scheme (ETS) emissions in 2014 (EPA [Environmental Protection Agency], 2016a). Under the European Union emissions reductions targets, Ireland must reduce emissions by 30% by 2030 (European Commission, 2016), which will prove a significant challenge for Ireland, especially in light of the agricultural production ambitions described above (Lynch *et al.*, 2016). Nitrogen losses to water are also currently under focus in Irish agriculture, as although the quality of water bodies in Ireland is generally quite good in comparison to other EU member states, there has been a significant decline in the number of rivers at the highest water quality as defined under the Water Framework Directive (EPA [Environmental Protection Agency], 2016b), with agriculture suspected as the cause of river pollution in over 50% of cases in the most recent assessment period (Bradley *et al.*, 2015).

This paper explores some of these issues by comparing economic and environmental performance for Irish farms from the most recent Teagasc National Farm Survey. By comparing farm profitability with environmental performance, the potential for sustainable intensification to provide both economic and environmental efficiencies is addressed, while differences in environmental metrics on a per farm and per unit output basis highlight the opportunities and difficulties to be considered in the current policy context.

## Methods

### *Data*

Farm data were obtained from the 2015 Teagasc National Farm Survey (NFS). The NFS fulfils Ireland's data collection for the Farm Accountancy Data Network (FADN), and as such is harmonised with similar farm level information collected across other European Union Member States. Due to differences in nitrogen fertilisation and prices per unit output which would not be adequately tracked by the approaches below, organic farms were omitted from the analyses. Mixed farms (farms where no individual enterprise accounted for more than two thirds of standard output following standard FADN groupings) were excluded in order to reliably relate farm level characteristics with specific forms of production. Farms importing or exporting manure were also excluded in order for nitrogen balances to reliably be estimated. After these exceptions, a total of 818 farms were included in the analysis, comprising 314 dairy, 330 drystock cattle, 110 sheep and 64 arable farms.

### *Economic measures*

Farm financial performance was measured using farm Gross Margin per hectare, and Family Farm Income per unpaid labour unit. Gross margin represents the farm gross output minus direct costs, and is expressed per hectare of utilised agricultural area to account for differences in farm size. Family Farm Income represents the farm gross output less direct and overhead costs, and is expressed per unpaid labour unit, whereby one labour unit represents a person over 18 years of age working for at least 1800 hours in the survey year. Labour unit equivalents of 0.75 and 0.5 are used for persons aged 16-18 and 14-16 respectively, and each age scaled labour unit cannot be exceeded even if more than 1800 hours are worked.

### *Environmental measures*

#### *Nitrogen Balance*

A farm-gate level nitrogen in-out accounting methodology was used to estimate nitrogen balance (Buckley *et al.*, 2015). Nitrogen (N) applied in synthetic fertilisers is recorded directly in the NFS. Milk N content is calculated from the quantity of milk protein supplied per farm, recoded in the NFS as provided by milk processors. N content of all other agricultural inputs and outputs is estimated based on weight using standard N content coefficients, with livestock weights estimated from total sale and purchase price for fattening or finishing animals, or per animal type for breeding stock. The farm N balance is then calculated as the difference between total N inputs and total N outputs. Nitrogen balance is considered an indicator of potential nitrogen surplus lost to the environment, and hence a risk factor in pollution of water bodies.

#### *Greenhouse Gas Emissions*

Greenhouse gas (GHG) emissions were estimated using the Intergovernmental Panel on Climate Change (IPCC) methodologies as described in the 2015 Irish National Inventory Report (Duffy *et al.*, 2015b), applied at individual farm level. Enteric fermentation methane ($CH_4$) emissions were estimated from livestock inventories by multiplying the numbers of livestock of category (scaled according to length of time present on farm) by the relevant NIR inventory coefficient for each animal type. Manure management methane emissions were estimated via the same approach using the appropriate NIR methane manure coefficients for each livestock category.

In order to derive manure based nitrous oxide ($N_2O$) emissions, annual N excretion was estimated and allocated to pasture, solid manure storage or liquid manure storage for each livestock category using NIR coefficients. Manure management $N_2O$ emissions were then estimated using the appropriate livestock by manure type coefficients from the NIR. Additional gaseous N losses from manure (NO, $N_2$ and $NH_3$) were calculated according to the Environmental Protection Agency Informative Inventory Report (Duffy *et al.*, 2015a), in accordance with the NIR methodologies. Remaining N was then assumed applied to managed agricultural soils, and relevant $N_2O$ soil emissions coefficients used. Finally, $N_2O$ emissions resulting from application of synthetic fertilisers were estimated by multiplying the standard Irish $N_2O$ emissions factor for synthetic fertilisers by the quantities applied as recorded in the NFS.

Emissions were allocated between enterprises based on livestock numbers and fertiliser applications. A proportion of emissions associated with dairy were assigned to beef production based on the relative economic value of culled cows and surplus calves compared to milk revenue.

For reporting purposes, all greenhouse gas emissions are reported in carbon dioxide equivalents ($CO_2e$) according standard IPCC global warming potential conversions factors of 298 kg $CO_2e$ per kg $N_2O$ and 25 kg $CO_2e$ per kg $CH_4$.

These environmental metrics were analysed at both a per farm level and, for livestock farms, per unit output. Per farm emissions and nitrogen balances were described per hectare of utilised agricultural area. Disaggregated GHG emissions per unit agricultural output were described per kg of relevant product (milk or livestock liveweight offtake). Disaggregated nitrogen balances were related to individual outputs based on the quantity of relevant product obtained for each kg of surplus nitrogen applied. Milk outputs were converted to fat and protein content corrected milk (FPCM), with actual protein and fat contents (provided by dairy processors and recorded in the NFS) standardised relative to 4.0% fat and 3.3% protein using the following equation:

$$FPCM\ (kg) = milk\ (kg) \times (0.1226\ \times fat\% + 0.0776\ \times protein\% + 0.2354)$$

Drystock cattle and sheep liveweight offtakes were estimated as described above for nitrogen balance calculation.

***Statistical Analyses***

Correlations between whole farm environmental (GHG emissions per hectare and N balance per hectared) and economic (gross margin per hectare and family farm income per unpaid labour unit) were tested using Spearman's rank correlation for all farm types. Disaggregated emissions and nitrogen surpluses per unit product of milk, cattle liveweight offtake and sheep liveweight offtake were also compared with farm gross margins and FFI per labour unit. Disaggregation was not undertaken for arable farms due to the diversity of crop types between them. All analyses were performed in R (R Core Team, 2016).

## Results

### *Dairy Farms*

More profitable dairy farms emitted more greenhouse gas emissions and applied greater nitrogen surpluses per unit area (fig 1). Greater agricultural GHG emissions per hectare positively correlated with both gross margin per hectare (fig 1a, $r_s$ = 0.74, $p$ <0.001) and family farm income per labour unit ($r_s$ = 0.29, $p$ <0.001, data not shown). Higher nitrogen balances were also positively correlated with both gross margin per hectare (fig 1b, $r_s$ = 0.49, $p$ <0.001) and family farm income per labour unit ($r_s$ = 0.23, $p$ <0.001, FFI data not illustrated).

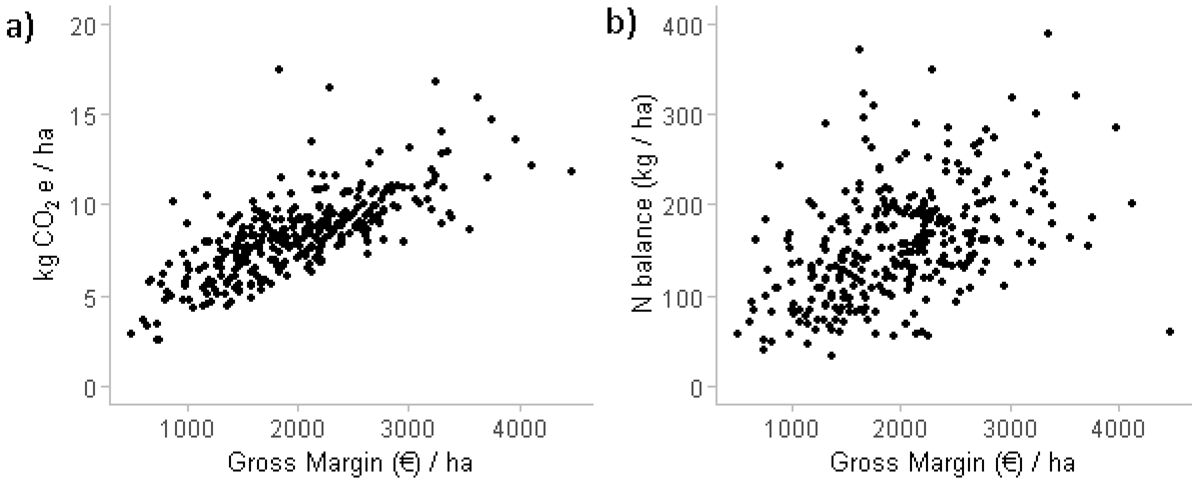


**Figure 1. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per hectare and b) nitrogen balance per hectare for dairy farms in the 2015 Irish National Farm Survey**

Per unit of fat and protein corrected milk (FPCM) output, however, more profitable farms were more emissions and nitrogen efficient (fig 2). Dairy based agricultural GHG emissions per kg FPCM were negatively correlated with both gross margin per hectare (fig 2a, $r_s$ = -0.43, $p$ <0.001) and family farm income per labour unit ($r_s$ = -0.33, $p$ <0.001). Greater quantities of FPCM per kg surplus nitrogen applied were positively correlated with both gross margin per hectare (fig 2b, $r_s$ = 0.21, $p$ <0.001) and family farm income per labour unit ($r_s$ = 0.17, $p$ <0.01).

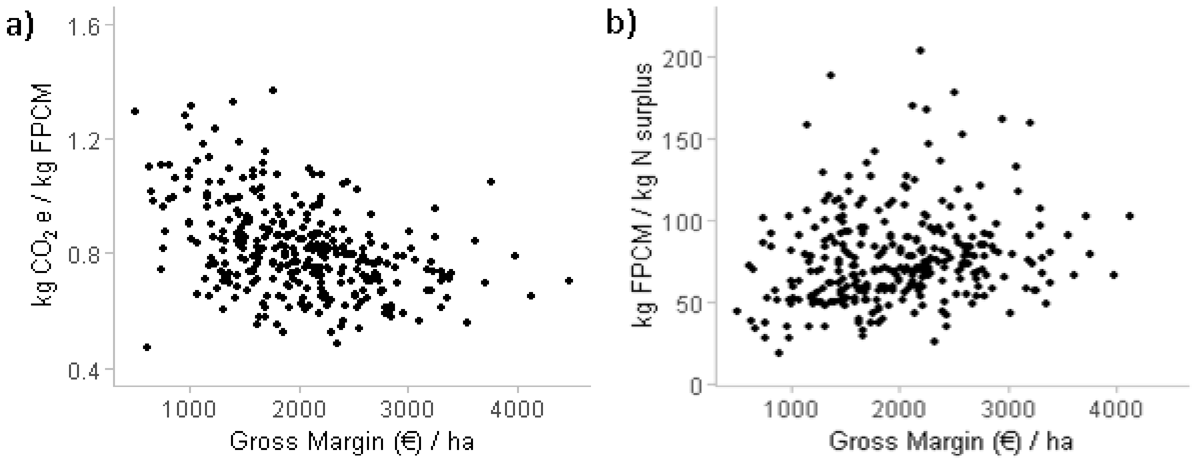


**Figure 2. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per kg fat and protein corrected milk (FPCM) output and b) kg FPCM output obtained per kg surplus N**

## *Cattle Farms*

Cattle farm profitability was also associated with greater GHG emissions and nitrogen surpluses per unit area. Agricultural GHG emissions per hectare were positively correlated with both gross margin per hectare (fig 3a, $r_s$ = 0.66, $p$ <0.001) and family farm income per labour unit ($r_s$ = -0.20, $p$ <0.001). Greater nitrogen balances per hectare were correlated with increased gross margin per hectare (fig 3b, $r_s$ = 0.45, $p$ <0.001), but the relationship with family farm income per labour unit was not significant ($r_s$ = 0.09, $p$ =0.07).

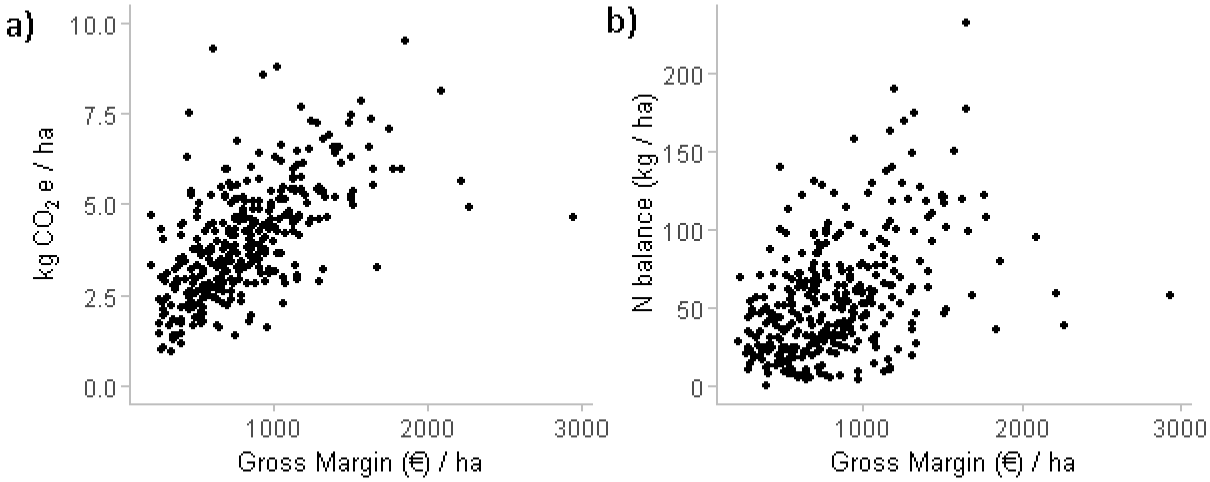


**Figure 3. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per hectare and b) nitrogen balance per hectare for cattle farms in the 2015 Irish National Farm Survey**

More profitable cattle farms were more environmentally efficient per kg beef liveweight offtake. Agricultural emissions associated with beef production per kg offtake were negatively correlated with both gross margin per hectare (fig 4a, $r_s$ = -0.46, $p$ <0.001) and family farm income per labour unit ($r_s$ = -0.33, $p$ <0.001). Cattle liveweight offtake per kg surplus N applied was also positively associated with both gross margin per hectare (fig 4b, $r_s$ = 0.25, $p$ <0.001) and family farm income per labour unit ($r_s$ = 0.23, $p$ <0.001).

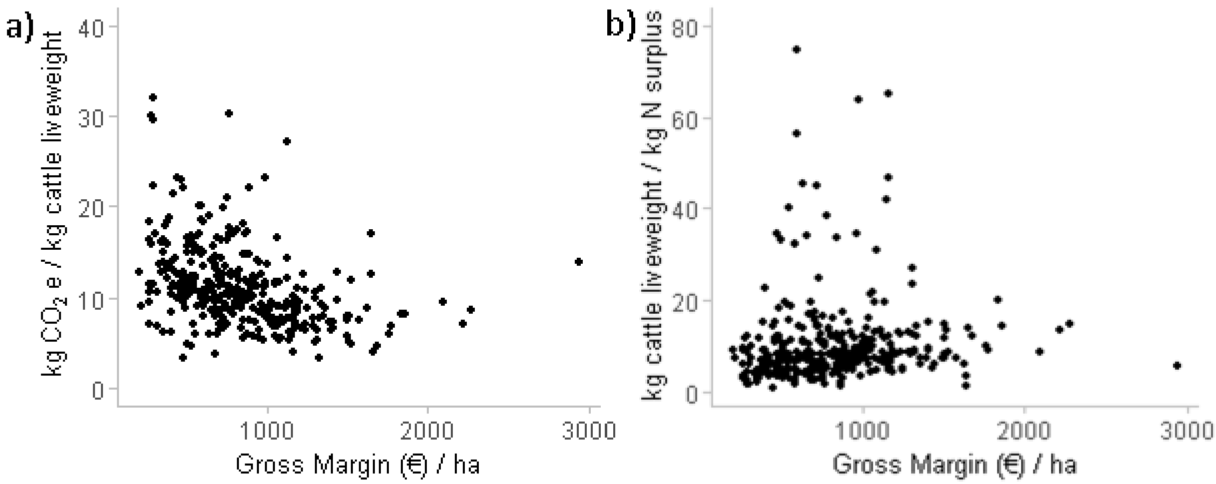


**Figure 4. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per kg cattle liveweight offtake and b) kg cattle liveweight offtake obtained per kg surplus N**

***Sheep Farms***

Agricultural emissions per hectare were positively correlated with both gross margin per hectare (fig 5a, $r_s$ = 0.83, $p$ <0.001) and family farm income per labour unit ($r_s$ = 0.26, $p$ <0.01) on sheep farms. Nitrogen surpluses per hectare were also positively correlated with gross margin per hectare (fig 5b, $r_s$ = 0.58, $p$ <0.001), but not significantly correlated with family farm income per labour unit ($r_s$ = 0.06, $p$ =0.5).

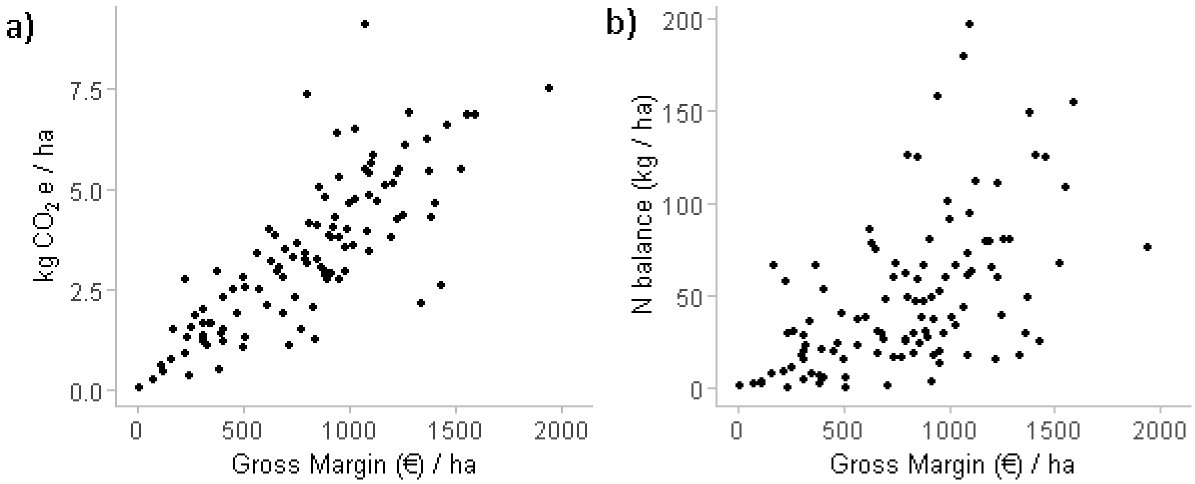


**Figure 5. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per hectare and b) nitrogen balance per hectare for sheep farms in the 2015 Irish National Farm Survey**

In common with cattle farms, sheep based agricultural emissions per kg sheep liveweight offtake were negatively correlated with both gross margin per hectare (fig 6a, $r_s$ = -0.45, $p$ <0.001) and family farm income per labour unit ($r_s$ = -0.26, $p$ <0.001). Sheep liveweight offtake per kg surplus N applied was positively correlated with farm family income per labour unit ($r_s$ = 0.24, $p$ =0.01), but was not significant in relation to gross margin per hectare (fig 6b, $r_s$ = 0.13, $p$ =0.19).

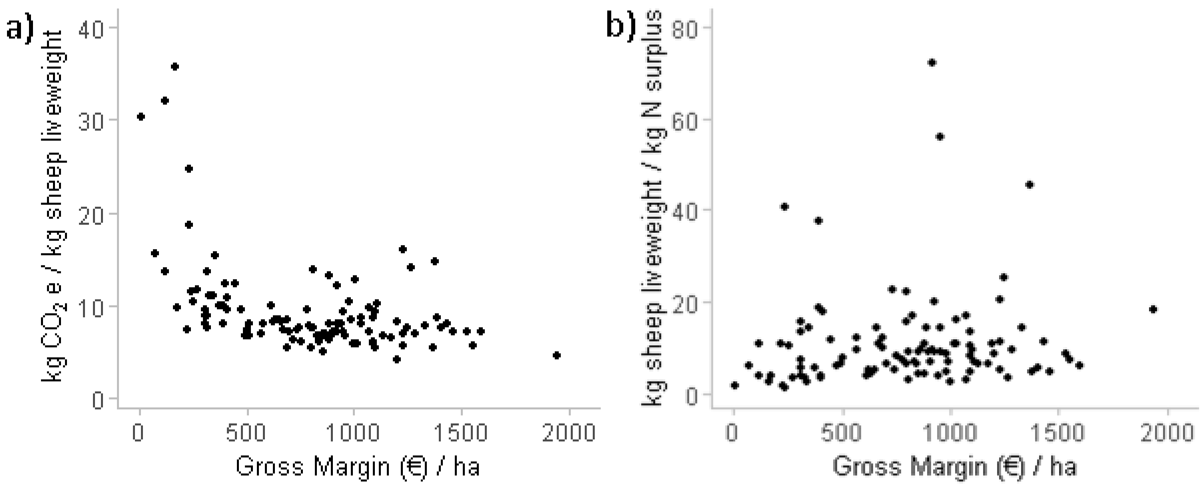


**Figure 6. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per kg sheep liveweight offtake and b) kg sheep liveweight offtake obtained per kg surplus N**

***Arable Farms***

Arable farms showed a positive correlation between agricultural greenhouse gas emissions per hectare and gross margin per hectare (fig7a, $r_s$ = 0.32, $p$ =0.01), but not with family farm income per labour unit ($r_s$ = 0.04, $p$ =0.78). Nitrogen balances per hectare were not correlated with gross margin per hectare (fig 7b, $r_s$ = 0.21, $p$ =0.1) or family farm income per labour unit ($r_s$ = -0.11, $p$ =0.39).

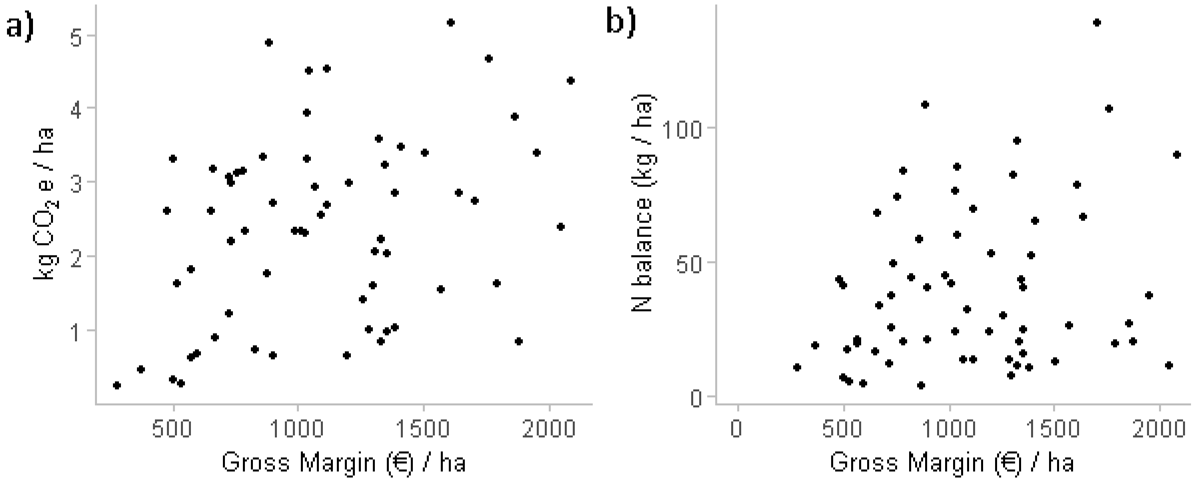


**Figure 7. Relationship between farm gross margin per hectare and a) agricultural greenhouse gas emissions per hectare and b) nitrogen balance per hectare for arable farms in the 2015 Irish National Farm Survey**

Due to the smaller sample size for arable farms (reflecting the relative numbers of arable to livestock farms in Ireland), and the disparity in crops grown among the sample, per unit output analyses were not performed for arable farms in this study.

**Discussion**

The results above show a clear trend for better economic performance to be associated with greater greenhouse gas emissions and nitrogen surpluses per hectare. This is a result of these economically better performing farms generally being more intensive, with higher stocking rates resulting in more livestock based emissions, and higher fertiliser application rates increasing fertiliser based emissions per hectare and resulting in larger nitrogen surpluses per hectare. This result would appear to support the concerns raised in the introduction that the national policy ambition to increase agricultural output (DAFM [Department of Agriculture Fisheries and Food], 2015) may be coming at the cost of increased greenhouse gas emissions and nitrogen losses to the environment (EPA [Environmental Protection Agency], 2016b). Increases in agricultural production since 2011 have resulted in an increase in agricultural GHG emissions, primarily due to increases in the size of the national cattle herd over this period (Duffy *et al.*, 2016).

Expressed per unit agricultural output, however, there was a consistent trend for better economically performing farm to have reduced environmental impacts. Farms with better economic performance were associated with lower greenhouse gas emissions per kg livestock offtake or milk produced, and achieved greater levels of agricultural production for every kg surplus nitrogen applied. These trends offer potential evidence for sustainable intensification to yield economic and environmental 'win-wins' through improved efficiency.

These two opposing trends pose difficulties in Ireland's current policy environment. Although it may be that increased production is being achieved in a more sustainable manner, with, for example, reduced greenhouse gas emissions per unit agricultural output, unless significant net reductions are made then Ireland will fail to meet its challenging emissions targets (Lynch *et al.*, 2016). It has been argued that the policy framework should be changed to prioritise food production where it can be achieved most efficiently, via allocation of emissions and relevant targets or policy incentives (e.g. a carbon tax) to consumers, rather than producers (Hennessy, 2017). This consumption based approach is an emerging topic, and has also been suggested for embedded nitrogen pollution (Galloway *et al.*, 2014; Oita *et al.*, 2016) and biodiversity losses (Kitzes *et al.*, 2016). Implementing such systems, however, would be a significant change from current international commitments and policy arrangements, but could also be driven by changes in consumer demand.

The different relationships between farm economic and environmental performance depending on whether metrics are examined per unit area or per unit output also highlight wider debates relating to the adoption of sustainable intensification. Targeted, intensive production can provide the means to minimise impacts per unit agricultural output (Tilman *et al.*, 2011), and although emissions per unit area farmed may be greater, less productive land can be taken out of agriculture and used to provide alternative environmental benefits, such as biodiversity conservation (Phalan *et al.*, 2011): a 'land-sparing' approach. However, it has also been argued that rather than prioritisation of intensive land use, 'land-sharing' should be adopted, providing additional multifunctional benefits from agricultural systems, particularly in Europe, where many species rich habitats are associated with the maintenance of less intensive production systems (Plieninger *et al.*, 2006). In practice, options need to be considered that range between these two approaches, and the most appropriate strategy is dependent upon both the objectives prioritised and viability of different land uses in a given location (Law and Wilson, 2015). These debates are complex, but the metrics demonstrated here highlight some of the means by which emerging trade-offs and synergies can be understood and assessed. These approaches are especially timely in the context of continued CAP reform (with an increasing emphasis on environmental impacts) and the implications of greenhouse gas emissions reduction targets for agricultural production.

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