The development of farm-level sustainability indicators for Ireland using the Teagasc National Farm Survey

Mary Ryan[1]*, Cathal Buckley[2], Emma Jane Dillon[1], Trevor Donnellan[1], Kevin Hanrahan[1], Thia Hennessy[1] and Brian Moran[1].

[1]Agricultural Economics and Farm Surveys Department, Teagasc, Athenry, Co. Galway, Ireland.
[2]Crops, Environment and Land Use Programme, Teagasc, Athenry, Co. Galway, Ireland.

Contributed Paper prepared for presentation at the 88th Annual Conference of the Agricultural Economics Society, AgroParisTech, Paris, France

9 - 11 April 2014

*Mary Ryan, Agricultural Economics and Farm Surveys Department, Rural Economy and Development Programme, Teagasc, Athenry, Co. Galway, Ireland.
Email: *mary.ryan@teagasc.ie*

Acknowledgements: The authors wish to thank colleagues for their advice and staff involved in the collection and validation of Teagasc National Farm Survey data and the farmers who participate voluntarily. Any errors or omissions remain the responsibility of the authors.

Abstract

Developing the capacity to assess and chart trends in the sustainability of farming and food production is becoming increasingly more important as agriculture strives to produce more food while minimising the risk to the natural environment. The multi-faceted nature of sustainability is encompassed in economic, environmental, social and innovation indicators. This paper outlines the development of farm level indicators for these sustainability criteria in Ireland. A comparison of indicators across farm systems shows that dairy farms, followed by tillage farms, tend to be the most economically and socially sustainable farm systems. Interestingly, in relation to greenhouse gas emissions in particular, the top performing farms in an economic sense also tend to be the best performing farms from an environmental sustainability perspective. This trend is also evident in terms of the adoption of innovative practices on farm, which is found to be strongly positively correlated with economic performance.

Keywords Agriculture, Sustainability

JEL code Agricultural Economics, micro-analysis Q12, Q18, Q56

Introduction

An increasing number of "Grand Challenges" for food and agriculture have emerged in the first decade of the 21st century. These include population growth, climate change, energy and water supply, all of which affect the potential of agriculture to provide a secure supply of safe food for a rapidly growing population. Clearly, international efforts to reduce greenhouse gas (GHG) emissions will need to take account of emissions from the entire food chain including agriculture. At the same time, an increase in global food production is needed. As a result, "sustainable intensification" of agricultural production is emerging as a priority for policymakers and international development agencies (Herrero and Thornton, 2014).

Sustainable development was defined in the Bruntland report as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987). Sustainability was the main principle of the declaration of the Rio Earth Summit and Agenda 21, established in 1992 at the United Nations (UN) Conference for Environment and Development, which established a mandate for the UN to formulate a set of indicators to gauge progress towards sustainability (Dillon et al, 2010). Since then there has been a concerted effort to monitor progress towards sustainable development, using indicators of sustainable land management, land quality indicators, (Rigby et al., 2001) and indicators of sustainable agriculture (Frater and Franks, 2013).

In the agricultural sustainability context, a comprehensive international literature review was undertaken by (Dillon et al., 2007), and later (Dillon et al., 2010) initializing the process of analysing Irish farm level data to assess the sustainability of Irish agriculture. It is only very recently that the collection of additional data allows for the augmentation of this initial suite of Irish sustainability indicators. Recently also, there has been a recognition of the role of innovation as an indicator of the longer term sustainability of agricultural practices. This paper builds on previous work to deepen and broaden the measurement of farm sustainability, encompassing economic, environmental, and social indicators, while also undertaking the development of indicators of innovation based on the adoption of new or innovative farm practices. We describe the sustainability criteria to be measured and the variables used to develop the relevant indicators for the main farm systems, namely dairy, cattle, sheep and tillage. The indicators are examined by system and aggregated nationally to facilitate more detailed analysis and discussion of results.

Background

The goal of the EU Bioeconomy Strategy –'Innovating for Sustainable Growth' (EC, 2012) is to move to a more innovative and low emissions economy, reconciling demands for sustainable agriculture, food security, while ensuring biodiversity and environmental protection. For a country of just 4.5 million people, Ireland has a large agri-food sector based mainly on exports. Of the total land area, 81 percent is devoted to agriculture, which is predominantly pasture devoted to dairy and dry-stock production, sufficient to feed around thirty million people (Govt. of Ireland, 2012). This production is facilitated by favourable climatic conditions for the growing of grass, allowing farmers to benefit from a natural, low-input production system. Irish farming is not particularly intensive in nature. According to the Teagasc National Farm Survey for 2012, the average farm size across all systems in 2012 was 47 hectares (ha) and the average income was €541 per hectare. There is a heavy reliance on direct payments across all farm systems, with the Single Farm Payment accounting for on average 87 percent of income for the cattle other system and on average 35 percent of dairy income (Hennessy et al., 2013a).

Projections suggest that the world's population will rise from the 2012 figure of seven billion to over nine billion by 2050 (FAO, 2009). This increase in global population is being accompanied by growth in real-income that is leading to a change in consumption, with meat and other livestock products becoming more prominent in the diet as incomes rise. The industry-developed strategy for the food sector in Ireland, Food Harvest 2020 (DAFM, 2010), maps the desired future direction of the agri-food and drinks sector for the next decade and points to the challenges and opportunities that lie ahead. One of the most pressing challenges for Irish agriculture will be to produce more food without negatively impacting on the environment. Significant opportunities for the sector will arise from 2015 with the reform of the Common Agriculture Policy (CAP), which will allow for increased milk production within the EU. Dillon et al. (2014) examines the specific challenges facing the Irish dairy sector in expanding production in a sustainable manner.

There is a growing awareness of the need to capture international food market opportunities in a sustainable way that minimises the impact on land use and GHG emissions. Ireland's food marketing board (Bord Bia) has built its "Origin Green" marketing campaign on Ireland's extensive, low-input, grass-based production systems. In the more mature EU and US markets, consumers are increasingly seeking foods with clear and credible health, wellness and sustainability attributes. Consumers who demand the highest quality in food production and environmental standards expect clear visibility on sustainability issues and, crucially, are willing to pay a premium for this. Large retail outlets are also demanding that their food suppliers demonstrate the principles of sustainability and traceability in their food products Government of Ireland, 2012).

In 2012 about 30 percent of Ireland's GHG emissions came from the agriculture sector (EPA, 2013), whereas the corresponding EU average in 2010 was just over 10 percent (Donnellan, 2014). The extent of beef and dairy production gives agriculture prominence as a source of Irish GHG emissions (Breen et al., 2010)[1]. However, on a like-for-like product basis, GHG emissions generated in Irish agricultural production are among the lowest internationally. A study by the European Commission has shown that Irish agriculture has the lowest carbon footprint in the EU for milk, and the fifth lowest carbon footprint in the EU for beef (Leip et al., 2010). In this context, the measurement of the relative sustainability of Irish agriculture and Irish food exports has recently gained increased policy prominence.

Methodology

[1] These GHG emissions come from a variety of sources, including methane belched by cattle, methane and nitrous oxide from animal slurry, nitrous oxide from urine, and nitrous oxide from the use of nitrogen fertilisers. To put these emissions in context, it is worth noting that, over the course of a year, the methane emissions associated with a cow are comparable to the emissions produced from the fuel used in driving a typical family car.

Indicators of sustainability have been used to describe and measure key relationships between economic, social and environmental factors with sustainable development being seen as a balance between the dimensions of sustainability. Successful indicators are usually readily understandable, representative of key environmental policies and concerns, and capable of illustrating trends over time. In addition, indicators provide an early warning of potential future economic, social or environmental damage. They must be scientifically valid, analytically sound, measurable and verifiable. They depend significantly therefore, on the availability of adequate, good quality data, which is updated at regular intervals (FAO, 2003).

This study outlines the development of Irish farm-level sustainability indicators using 2012 Teagasc National Farm Survey (NFS) data. The NFS is a nationally representative weighted sample of over 1,000 Irish farms collected annually. The first NFS results were published in 1972, just ahead of Ireland's accession to the European Economic Community (EEC) and have been published on an annual basis since then. At that time, each Member State of the EEC also became members of the Farm Accountancy Data Network (FADN) which provides a harmonised platform for the collection of farm statistics across Europe. NFS data are particularly suitable for the design of indicators as the collection method is consistent and verifiable, both important issues for objective credible, national reporting. Furthermore, the longitudinal nature of the data makes it possible to chart indicators over time. In recent years, data collection in the NFS has been expanding in nature and complexity and is now much richer than that required for economic performance analysis for FADN purposes. Thus it is now possible to develop indicators to represent all four dimensions of sustainability namely, economic, environmental, social and innovation (Hennessy et al. 2013b). Additionally, the fact that the NFS is linked to FADN opens up the possibility of engaging in future international comparative studies.

Economic indicators

Given the wealth of economic data within the NFS the design of economic indicators is relatively straightforward. Although much of the focus in the sustainability debate is directed towards environmental resource management, farms must also be economically viable in the longer term. Farm level measures of sustainability that capture the broad concepts of productivity, profitability and viability are presented in Table 1.

Table 1. Economic Indicators

Indicator	Measure	Unit
Productivity of labour	Income per unpaid labour unit	€/labour unit
Productivity of land	Gross output per hectare	€/hectare
Profitability	Market based gross margin (less subsidies) per hectare	€/hectare
Market orientation	Proportion of output derived from the market	%
Farm viability	Farm is economically viable	1=viable, 0=not viable

The return to labour invested on the farm is measured as family farm income per unpaid labour unit employed on the farm. Family farm income includes a deduction for hired labour, hence the measure only includes unpaid family labour. An economically viable farm is defined as having the capacity to remunerate family labour on the farm at the average agricultural wage and the capacity to provide an additional five percent return on non-land assets.

Environment indicators

The need to produce more food without impacting negatively on the environment is possibly the greatest challenge facing the agricultural sector. The nature of the interactions between agricultural practices and the environment are complex and it will only be as scientific knowledge on these interactions grows that there will be greater clarity on the extent and nature of the data required for the future development of environmental indicators. While comprehensive economic data have been collected in the NFS for 40 years, the inclusion of environmental data is relatively recent. The environmental thematic areas which are of most concern include air quality and climate change; risk to water quality; and habitat and biodiversity indicators (EPA, 2013).

Air quality and climate change

Most scientists agree that GHG emissions are a major contributor to climate change. One of the most pressing challenges for Irish agriculture will be to produce more food without increasing these emissions. Agriculture is Ireland's single largest emissions source by sector, accounting for 32.1 percent of total GHG emissions in 2012 (EPA, 2013). The measurement, reporting and verification of GHG emissions from the agricultural sector are highly complicated from both a scientific and administrative perspective. Generally, there are two different commonly used approaches to measuring GHG emissions from agriculture and the agri-food chain. These are the Intergovernmental Panel for Climate Change (IPPC) methodology and the Life-Cycle Assessment (LCA) approach for agriculture. The standard method for reporting GHG emissions is the IPCC approach which is confined to measuring emissions that occur inside the farm gate and quantifies GHG emissions using a national sector-based approach. In the case of agriculture it confines itself to the emissions within the farm gate. Emissions associated with imported inputs, such as animal feed, fertiliser or farm animals are not included in this measure. The more holistic LCA is product rather than sector based and encompasses the length of the food chain from the production of agricultural inputs right through to the retailer and consumer[2].

The methodologies selected to measure GHG's are dictated largely by the availability of environmental data. Sufficient activity data are available within the NFS dataset to estimate GHG emissions associated with each farm enterprise using IPCC coefficients and conventions to produce an estimate of total emissions per farm. Once GHG emissions per farm are estimated, three emissions indicators are reported: total GHG emissions per farm, greenhouse gas emissions per unit of product and GHG emissions emanating from electricity and fuel use on the farm. Total farm emissions are presented as tonnes of carbon dioxide equivalent (CO_2-eq). Emissions per unit product are expressed in terms of CO_2-eq per kilograms (kg) of product

[2] For more detail on farm level LCA methodology, see Hennessy et al. (2013b).

produced. This is presented for the main product produced by the dairy, cattle and sheep systems. In the case of dairy and tillage farms actual kilograms of milk and crop production are recorded by the NFS. However, it was not feasible to develop per unit product indicators for tillage farms as further work is required to allocate emissions to the particular crops cultivated on the farm. For cattle and sheep farms it was necessary to estimate kilograms of output by using standardised animal weights and prices. This per unit product measurement approach allows for the incorporation of production efficiencies in the measurement of the indicators. Emissions from fuel and electricity used on the farm and by hired contractors also contribute to overall agricultural emissions. These emissions are estimated separately from the above indicators and are presented for the dairy, cattle and sheep systems in relation to the volume of output produced.

Risk to water quality

Inefficient use of nutrients on farms has significant economic implications for farmers as well as for the wider environment. Nitrogen (N) is one of the main elements underpinning agricultural production. However, surplus nitrogen poses a risk to the aquatic environment. All other things being equal, optimal use of nitrogen can deliver a double dividend of reduced risk of nutrient loss from agricultural land, thereby helping to achieve environmental water quality objectives while increasing the economic margins at farm level. The complexity of the interactions between agriculture and water quality are not yet fully understood, therefore developing relevant indicators on which data are available is particularly challenging. The links between nitrogen balance (imports of N less exports) at farm and field level and loss to the environment are complex and difficult to predict as the nature of the interactions depends on a myriad of factors such as soil type, hydrology, weather, farm structures and management practices.

Both farm gate and whole farm balance nutrient accounting approaches provide a reliable assessment of nutrient management efficiency at farm or enterprise level while providing an indicator of environmental pressure in terms of risk to water quality. The farm gate approach restricts analysis to imports and exports of nutrients over which the farmer has direct control (through the farm gate). Whole farm approaches additionally account for nutrient inputs and exports such as atmospheric deposition, biological fixation and mineralisation of nutrients in soils. Ideally, holistic whole farm soil/surface indicators would take account of the nutrient status of the soils but the full range of data required to undertake a whole farm balance analysis is not available within the NFS. However, farm gate nitrogen balances are a reliable indicator of agronomic efficiency and environmental pressure (Schroder et al., 2004).

Using the available data, a farm gate nitrogen (N) balance per hectare measure of the risk to water quality is developed for all systems. The farm gate N balance is established by subtracting the total quantities of N imported from total quantities of N exported on a per hectare basis. Each of the products exported from the farm (e.g. milk, meat, crops, wool) and imports (mainly chemical fertilisers and feedstuffs) are converted to kilogrammes of N using relevant coefficients (see Buckley et al. (2013). Farms importing or exporting organic manures were excluded from the analysis due to data limitations. Table 2 presents the environment indicators examined in this paper.

Table 2. Environment Indicators

Indicator	Measure	Unit
GHG emissions per farm	IPCC estimate/ farm	Tonnes CO_2-eq /farm
GHG emissions per kg of output	IPCC estimate/ kg of output	Kg /kg output
Nitrogen (N) balance	Risk to water quality	Kg N surplus/hectare
Emissions from fuel and electricity	CO_2-eq /kg output	Kg CO_2-eq /kg output

Habitat and biodiversity indicators

The measurement of biodiversity is a key component of any assessment of environmental sustainability. Many Irish farming systems have a relatively high proportion of habitats for farmland wildlife, and this is a feature of Irish agriculture that is a key selling-point in Ireland's "Origin Green" international agri-food marketing campaign. Measurement of these features will be required to translate farmland wildlife attributes into labelling and marketing initiatives. Aside from its intrinsic and cultural values, biodiversity has a functional value in the provision of services, e.g. food and fuel. In principle, methods for farm-scale assessment of wildlife habitats in Ireland are well developed (e.g. Sheridan et al. 2011), and the primary constraint is the logistical effort required to undertake habitat surveys.

Measurement of the number of land use types and their proportional abundance as reported in the NFS dataset could, in the future form the basis of a future biodiversity indicator; however the data collected on NFS farms is not currently sufficiently detailed for indicator development. The land use types recorded in the NFS range in intensity of farming from pasture and tillage to rough grazing and old woodland and can be used to measure the richness and evenness of land use diversity. However, these data do not contain information on the relative value of each land use in terms of the ecosystem services provided. Additional data needs to be collected and further work needs to be undertaken to investigate the weighting of each land use type in terms of its ecological quality, before meaningful indicators of farmland habitat can be developed.

Social indicators

In evaluating sustainability in the past, economic and environmental factors took precedence and income was commonly used as an indicator of social welfare in the literature. There is now a growing recognition of the need to examine overall human well-being and quality of life within the sustainability framework. Agriculture contributes to the viability of rural areas, helping to maintain the rural infrastructure. Social sustainability indicators are designed here to gauge the quality of life of the farming community by identifying and quantifying those 'social life' dimensions not determined by economic activity. Welfare is determined not only by economic activity but also by a wide range of additional dimensions of social life. Five indicators are presented in Table 3 that quantify the 'social life' dimensions as follows:

- *Household vulnerability:* A household is vulnerable if the farm is not economically viable[3] and neither the farmer nor spouse is employed off-farm.

[3] An economically viable farm has (a) the capacity to remunerate family labour at the average agricultural wage, and

- The *Education level* of farm household members is used as an indicator of the makeup of the household in the context of farm succession.
- *Isolation:* A household is classified at risk of isolation if the farmer lives alone.
- *Demographic Viability*: An examination of the age profile of farm households can also be indicative of demographic viability. A household is designated as being of high age profile if the farmer is aged over 60 and there is no household member less than 45 years.
- *Work Life Balance*: This is calculated by taking account of the hours worked by the farmer on the farm.

Table 3. Social Indicators

Indicator	Measure	Unit
Household vulnerability	Farm business is not viable – no off-farm employment	Binary 1=Yes, 0=No
Education level	Educational attainment: 1=primary, 2=secondary, 3=some agricultural ed. 4=agricultural cert., 5=higher level	Count variable 1-5
Isolation risk	Farmer lives alone	Binary, 1=Yes, 0=No
Demographic viability	Farmer is > 60 years and no household member <45	Binary 1=Yes, 0=No
Work life balance	Work load of farmer	Hours worked on farm/week

Indicators of innovation

Innovation in agriculture has a key role to play in producing more food without depleting natural resources. To remain competitive, farmers need to innovate continuously so as to adapt to market developments and changes in resource quality and availability. Innovation is a broad concept but it is fundamentally about embracing novelty, which can be *"new to the firm, new to the market or new to the world"* (OECD and Eurostat, 2005). Innovation can be one of five main types: new processes, new products, new organisational forms, entering new markets or using new supply sources. Innovation is a broad concept but is fundamentally about embracing novelty (OECD and Eurostat, 2005) and can be used to gauge what farmers may be doing today that will impact on their future sustainability. At the farm level, many innovations are process innovations as they relate to the use of new production techniques, e.g. the use of improved seeds or the adoption of management practices that optimise resource efficiency (land, animals, nutrients, human capital and technology) thereby reducing impacts on the environment, but also reducing production costs. By contrast, organisational innovations include farm partnerships and share farming.

Adoption is defined by Leeuwis (2004) as the uptake of innovation by individuals. Research and business input into farm level innovation, but actual innovation only occurs when farmers put something new into use. Farm extension advisers facilitate the diffusion of innovation amongst farmers in order to improve production efficiencies and overall sustainability. In this context, NFS data on the adoption of new

(b) the capacity to provide an additional 5 percent return on non-land assets, (Frawley and Commins, 2000).

technologies or participation in knowledge transfer programmes are used to develop measures of farm innovation. As innovations are generally specific to the farm enterprise, indicators which are appropriate to each of the farm systems are developed.

- The dairy measures chosen were: participation in a milk recording programme which provides feedback on milk quality; membership of a dairy discussion/knowledge transfer group; and farmers who have changed the timing of slurry spreading to avail of greater uptake of nutrients during the early growing season[4].
- For cattle and sheep farms, the measures chosen were: membership of a beef or sheep Quality Assurance Scheme; undertaking of reseeding to improve grassland within the last three years; and the undertaking of soil testing within the last three years.
- On tillage farms, the measures chosen were: availing of forward selling of tillage crops; usage of ICT on the farm; and the undertaking of soil testing within the last three years.

Aggregation of indicators

Up to 25 farm-level sustainability indicators (both quantitative and qualitative) are developed for each farm system and aggregated nationally. In the results section which follows, average values are presented for each indicator across each system. The standard deviation which is a measure of the dispersion of the data around the mean is also presented. As the indicators developed in this analysis are both qualitative and quantitative in nature, measuring different concepts and using different scales, it is necessary to normalise the data and bring the various indicators to a common scale. Normalisation is performed using the MIN-MAX approach (OECD, 2008) whereby the lowest value for each indicator is subtracted from the value for a given observation and divided by the range of the dataset for that indicator. Indicators are then scaled from zero to 100, zero indicating the poorest performance in the sample and 100 indicating the best performance. The normalised indicators are then presented using spider diagrams which show the relative performance of the various farm systems along each dimension of sustainability.

Composite indicators

Indicators can take account of the various dimensions of sustainability separately, or they can encapsulate all these components in frameworks of indicators. The various indicators can be combined to arrive at one indicator for each of the dimensions of sustainability, for example one economic, one social, one innovation and one environmental indicator per farm. It is also possible to aggregate all of these indicators so as to arrive at one composite measure of farm-level sustainability for each farm or for the farming sector as a whole. However, there is much debate in the literature (Gomez-Limon and Riesgo (2009), Gomez-Limon and Sanchez-Fernandez (2010), Reig-Martinez et al. (2011)) surrounding the calculation and use of composite indicators with many

[4] Farmers who opt to spread more than 50 percent of slurry during February/March/April benefit from both economic and environmental dividends as there is a greater uptake of nutrients by grassland during these months, thereby reducing the requirement for chemical fertiliser and the risk of runoff of nutrients to water bodies.

claiming they over-simplify a complex issue. Further work needs to be undertaken to investigate the usefulness of composite indicators in an Irish context.

Results – economic sustainability

Table 4 presents the mean and standard deviation (SD) for the economic indicators for each of the farm systems in 2012. As expected, the dairy system is the most profitable of the farm systems. The average productivity of land (gross output per hectare) and market profitability (market based gross margin per hectare) are €3,069 and €1,440 respectively, with an average productivity of labour (income per labour unit) of €38,225. The market orientation of dairy farms (the proportion of output value derived from the market, as distinct from subsidies) is 85 percent on average.

Table 4. Economic sustainability indicators (2012)

Farm system	**Productivity of labour** €/labour unit	**Productivity of land** €/ha	**Market Profitability** €/ha	**Farm viability** %	**Market Orientation** %
	Mean (SD)	**Mean** (SD)	**Mean** (SD)	**Mean** (SD)	**Mean** (SD)
Dairy	**38,225** (28034)	**3,069** (984)	**1440** (619)	**69** (46)	**85** (7)
Cattle	**15,742** (19986)	**1,251** (552)	**433** (306)	**25** (43)	**60** (13)
Sheep	**16,629** (13975)	**1,281** (599)	**484** (328)	**24** (43)	**55** (17)
Tillage	**43,098** (32279)	**1,854** (690)	**840** (519)	**72** (45)	**74** (8)

On cattle[5] and sheep farms, the average gross output per hectare is €1,251 and €1,281 respectively, while the market gross margin is €433/ha for cattle and €484/ha for sheep. The average income per labour unit on cattle farms is €15,742 with an average of €16,629 for sheep farms. On cattle farms, 60 percent of output is derived from the market with 55 percent from the market on sheep farms. In relation to economic viability, the tillage system has the highest proportion of economically viable farms at 72 percent on average followed by dairy farms at 69 percent, while on average only approximately a quarter of cattle and sheep farms are viable in 2012.

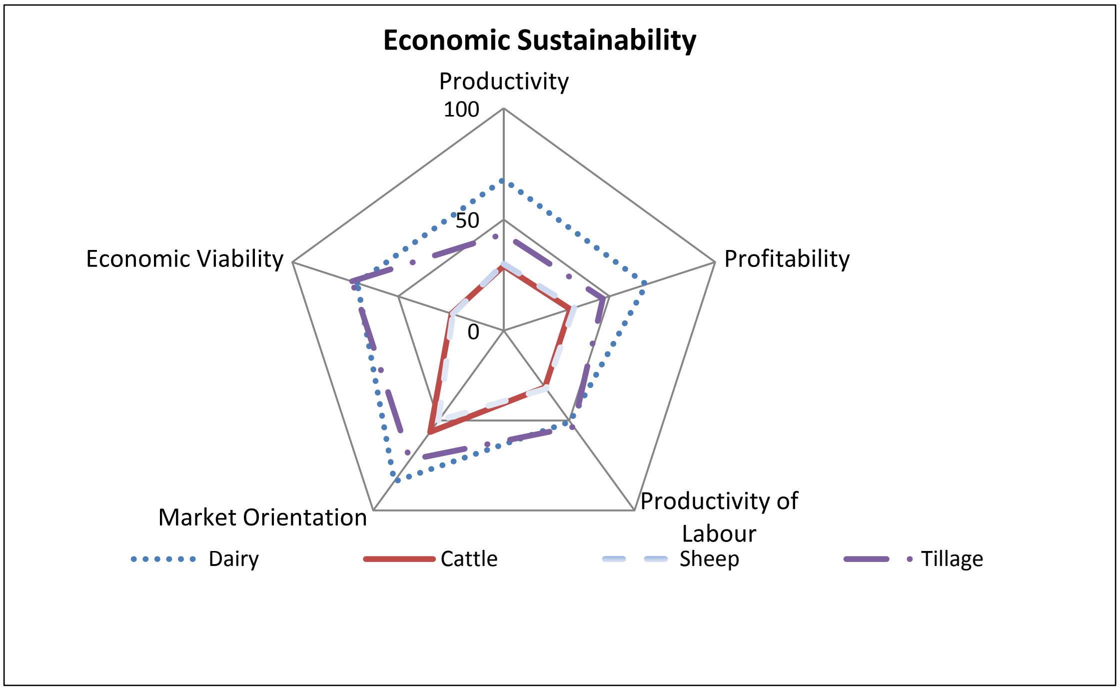
The average productivity of land on tillage farms is €1,854 per hectare and the average market gross margin is €840 per ha, however tillage farms have the highest income per labour unit (€43,098). Here there is wide variation around the mean with some tillage farms achieving an income per labour unit of almost €120,000. These are farms with very low labour input where most activities are contracted out. On average, 75 percent of output on tillage farms is derived from the market in 2012.

The spider diagram presented in Figure 1 facilitates the examination of the relative economic performance of the various farm systems for each dimension of economic sustainability by comparing the economic indicators for dairy, cattle, sheep and tillage

[5] The indicators for cattle farms combine cattle rearing and cattle finishing systems.

farms[6]. On average, dairy farms, followed by tillage farms, perform better along all of the economic indicators relative to the other farm systems. The performance of sheep and cattle farms is very similar, although sheep systems marginally outperform cattle in relation to productivity of land, productivity of labour and market profitability. The least variability in performance is exhibited along the market orientation dimension, where the four farm systems are clustered closest together.

Figure 1: Economic sustainability spider diagram



Results – environmental sustainability

The measures of GHG emissions were calculated using IPCC coefficients and conventions and include GHG emissions per farm and per kg of product. On dairy farms on average, approximately 61 percent of the emissions were generated by the dairy enterprise and 39 percent by cattle and other enterprises in 2012. On cattle farms, almost all of the emissions come from the cattle enterprise. Despite being specialised in sheep production, the cattle enterprise on sheep farms accounts for the larger proportion of emissions at 54 percent compared to 44 percent from sheep. Similarly, on specialist tillage farms, the cattle enterprise accounted for 63 percent of the emissions with cereal crops in general accounting for only 28 percent and the remainder accounted for by sheep or other crops. Further work is required to allocate the GHG emissions from tillage farms to the particular crops on the farm and to validate these results. Additional analysis is also required to allocate fuel and electricity usage to particular crops, as these are currently recorded on a whole farm basis and are not attributed to any particular crop.

---

[6] Spider diagrams are constructed so that zero, or poorest performance, is at the centre of the diagram and 100, or best performance is at the outer edge.

In Table 5 we see that on average dairy farms emitted 434 tonnes of carbon dioxide equivalent (CO_2-eq), while cattle farms on average emitted 143 tonnes of CO_2-eq per farm. The average sheep farm emitted 118 tonnes of CO_2-eq in 2012 and the tillage farm emissions average 139 tonnes of CO_2-eq. It is evident that the emissions from electricity and fuel account for only a small proportion of overall farm GHG emissions.

Table 5. Environmental sustainability indicators (2012)

Farm system	**GHG emissions per farm (tonnes CO_2-eq)**	**GHG emissions per kg of output**	**Nitrogen balance per ha**	**Fuel and electricity per kg of output**
	Mean (SD)	**Mean** (SD)	**Mean** (SD)	**Mean** (SD)
Dairy	**434** (246)	**0.77** (0.12)	**146** (63)	**0.06** (0.02)
Cattle	**143** (111)	**12.3** (5.49)	**54** (40)	**0.66** (0.40)
Sheep	**118** (95)	**7.3** (3.51)	**39.9** (28)	**0.44** (0.25)
Tillage[7]	**139** (144)	-	**53** (36)	-

Environmental indicators cannot be divorced from the economic performance of the farm. As previously stated, inefficient use of nutrients on farms has significant economic implications for farmers as well as for the wider environment. Measuring emissions per unit product allows for the incorporation of production efficiencies in indicator development. On this basis, Tables 6 and 7 present the emissions per kg product (milk, beef and lamb) and the nitrogen balance indicators (kg N surplus/ha) relative to the economic performance (on the basis of gross margin)[8] of the average of the top, middle and bottom one thirds of dairy, cattle and sheep farms.

Table 6. GHG emissions per unit product on the basis of economic performance

	Average	**Top**	**Middle**	**Bottom**
Dairy (CO_2-Eq kg/kg of **milk**)	0.77	0.71	0.75	0.85
Cattle (CO_2-Eq kg/kg of **beef**)	12.3	11.32	12.41	13.33
Sheep (CO_2-Eq kg/kg of **lamb**)	7.3	5.8	7.16	9.02

Table 6 shows the same trend across dairy, cattle and sheep farms. There is a large variation between the top and bottom performers, with the top economic performers producing the lowest emissions and the bottom performing group producing the highest emissions. These results show clearly the negative correlation between emissions and economic performance.

In Table 7, there is evidence of considerable variation between the top and bottom economic performers in the dairy system. The top performing dairy farms produce a considerably larger surplus of nitrogen on average (174.6 kg N/ha) than the less economic farms (118.5 kg N/ha). However these top performing dairy farms produce

[7]Per unit product indicators for tillage crops not included due to data limitations

more milk per kg of nitrogen surplus. The same trend is evident in the cattle and sheep systems, with top performers producing more surplus nitrogen, although with less variation between surplus nitrogen produced by the top and bottom performers. Sheep farmers on average have smaller nitrogen surpluses, particularly in the bottom group in which some of the more extensive sheep farms have a nitrogen surplus close to zero. The nitrogen balance results for tillage farms are more homogeneous than the results for livestock farms. There is very little variation in the mean values for the top, middle and bottom groups, varying from approximately 54.5 to 51.4 kg per hectare.

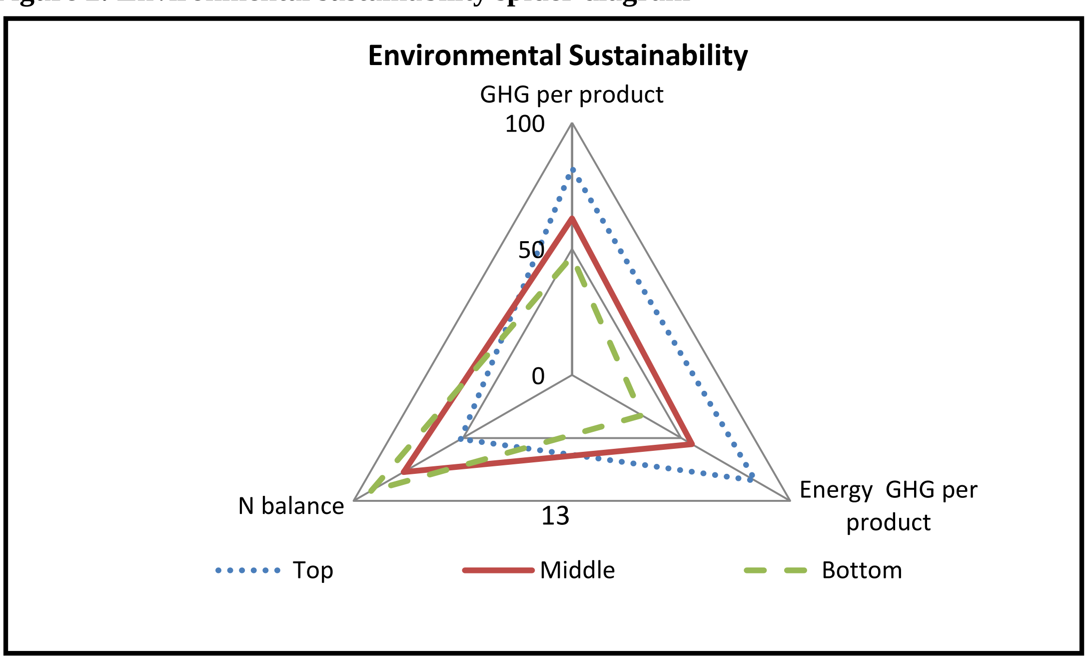
Table 7. Nitrogen balance per hectare (kg of N surplus/ha) on the basis of economic performance

	Average	Top	Middle	Bottom
Dairy (surplus N/ha)	146	174.6	145.1	118.5
Cattle (surplus N/ha)	54	71.03	44.4	49.04
Sheep (surplus N/ha)	39.9	49.6	41	27.6
Tillage (surplus N/ha)	53	54.5	53.5	51.4

These results are consistent with the more intensive production on these farms as the top performing farms produce relatively more product per kg of nitrogen surplus. However, it is indicative of greater risk of nutrient (N) losses to water as a result of the higher N surplus on the more intensive, economically efficient farms. It is also indicative of the positive correlation between intensity of production and risk to water quality.

From an environmental efficiency perspective, it is not very effective to compare different farm systems on an emissions per product basis, when the farm systems are producing very different products, i.e. kilograms of beef versus kilograms of milk. Here, environmental performance is examined within the farm system and farms are compared on the basis of their economic performance. Figure 2 shows the environmental performance of all farms on the basis of their economic performance within their own farm system.

Figure 2: Environmental sustainability spider diagram



In examining GHG emissions produced per unit of product, a correlation between economic and environmental performance is evident, i.e. the top performing farms economically emit less GHG emissions per kilogram of product than the bottom farms. The variation in performance is even more pronounced when GHG emissions from electricity and fuel are also considered. In their analysis, Hennessy et al. (2013b) found that across all farm systems, the top economic performing farms also tend to use energy and fuel more efficiently and hence have lower emissions per product. Only nitrogen balance per hectare is negatively correlated with economic performance. Along this criterion the bottom farms perform best by having the lowest nitrogen surplus per hectare.

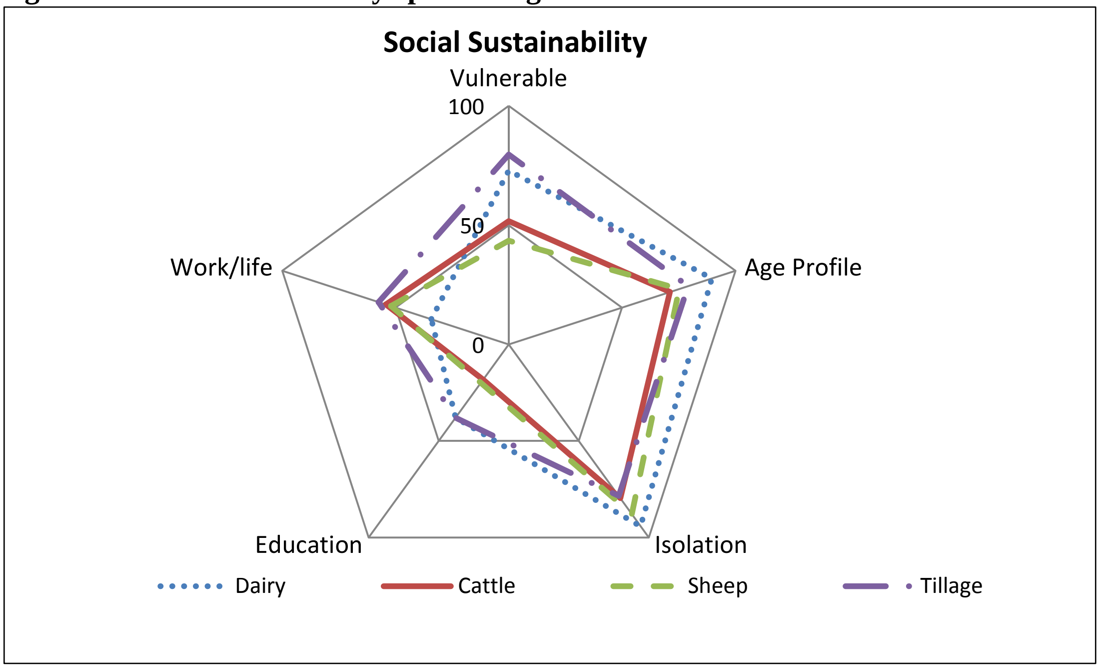
Results – social sustainability

In relation to social sustainability, dairy farming tends to be quite labour intensive. The work/life balance is represented by the number of hours worked by the typical farm operator in an average week, which is on average 47 hours on dairy farms, while cattle and sheep farmers work on average 32 and 34 hours per week respectively and tillage farmers have the lowest average working hours at just 30 hours per week.

In relation to farm household vulnerability the lowest proportion of vulnerable households are in the dairy system (15 percent) and tillage (18 percent) meaning that the farm business is not viable and there is no other source of income in the household. However, the proportion of vulnerable households is much higher for the cattle and sheep systems with over 40 percent of cattle and over 42 percent of sheep farms classed as economically vulnerable.

A similar trend is displayed in terms of the age profile of farmers. Where the farmer is nearing retirement but there is no obvious successor, the demography of farms is considered to be poor. This is the case on just 10 percent of dairy farms and on 20 percent of tillage farms, but there is evidence of poor demography on 28 percent of cattle farms and 25 percent of sheep farms.

Figure 3: Social sustainability spider diagram

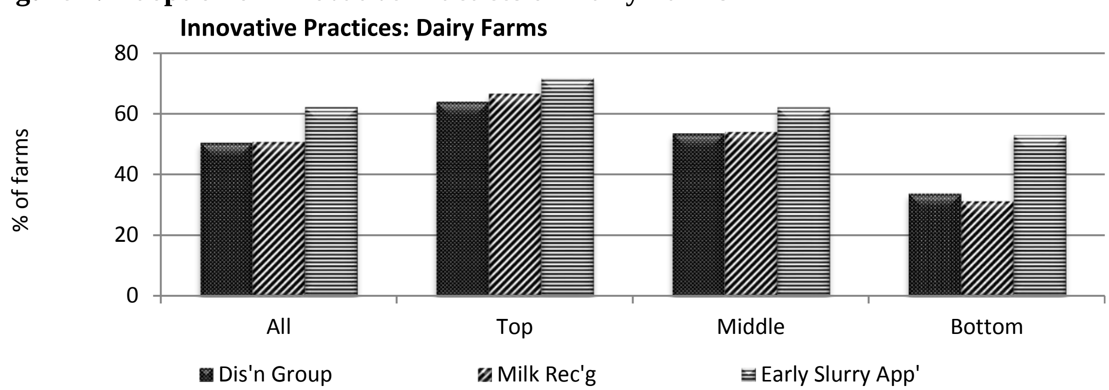


The social sustainability indicators for the farm systems are presented in Figure 3. While dairy and tillage farms perform better than the dry-stock systems along the social indicators, the differences between the systems are less pronounced than for the economic indicators. In particular, with regard to the demographic variables, high age profile and isolation tend to vary only slightly across the systems. Dairy and tillage farmers in Ireland also tend to be better educated than other farmers. The poor performance along the education indicator is likely to be a scaling issue (education is measured as a count variable with values from 1 to 5).

Results – innovation

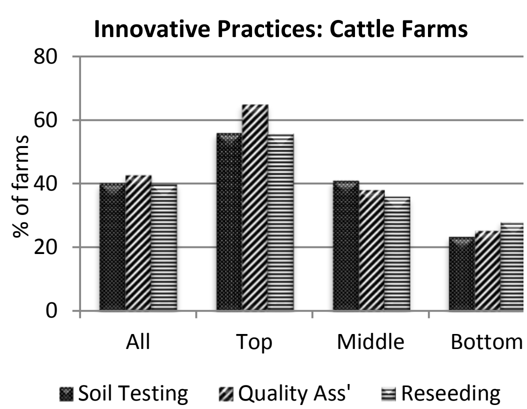
The indicators of innovation are farm specific and as such are not comparable across farm systems. Figure 4 shows adoption rates on dairy farms across all three selected practices are correlated with economic performance, although it is interesting that there is a relatively high rate of adoption of early slurry spreading, as this is a practice which is cost neutral to the farmer but gives both economic and environmental dividends and has been the focus of recent knowledge transfer programmes.

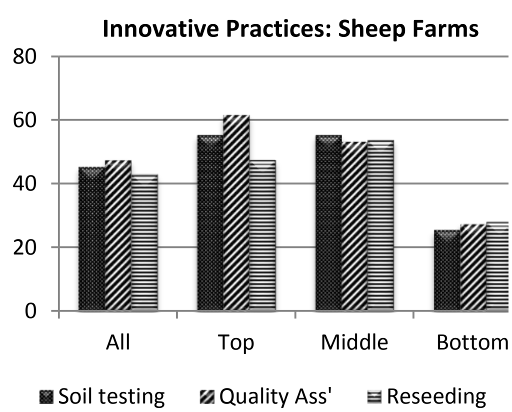
Figure 4: Adoption of Innovative Practices on Dairy Farms



Three innovative farm practices appropriate to both cattle and sheep farms were analysed. With regard to participation in the Beef and Sheep Quality Assurance Schemes, approximately 42 percent of all cattle and 47 percent of sheep farms participate. As is evident from Figures 5 and 6, participation tends to be highly correlated with economic performance. The other practices include soil testing and reseeding some grassland in the last 3 years.

Figures 5 and 6: Adoption of Innovative Practices on cattle and sheep farms (2012)

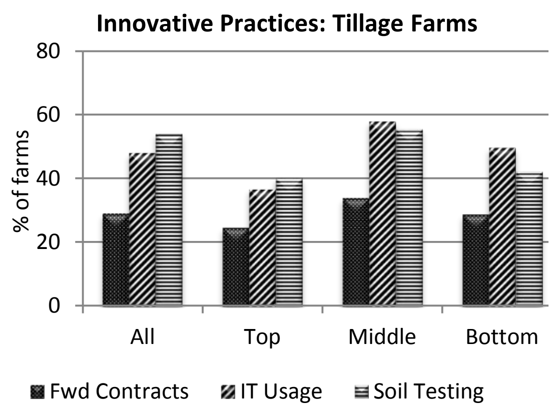




Adoption of these practices is also correlated with economic performance, with the top group having greater rates of adoption for all three practices.

Forward contracting has emerged as a relatively new and innovative means of managing price risk. Price volatility has been a major issue confronting tillage farms in the last number of years. As can be seen in Figure 7 an average of approximately 30 percent of tillage farms entered a forward contract in 2012. It is interesting that there is no strong relationship between the use of forward contracting and the economic performance of the farm. In fact the use of contracting is lowest for the top group. It should be borne in mind that in a given year, farmers will win or lose by entering a forward contract depending on the difference between the contract price offered, which is determined by the futures price, and the actual market price. Hence entering a forward contract can in itself determine the economic performance of the farm. The other farm practices considered were the use of a computer for farm business purposes and soil testing. Soil testing is highly positively correlated with economic performance, but the relationship between economic performance and IT usage is less pronounced.

Figure 7: Adoption of Innovative Practices on tillage farms (2012)



Discussion and conclusions

In assessing the sustainability of Irish farms across the selected indicators, we must recognise that the indicators may be in conflict with each other. The fact that a farm may be socially unsustainable (e.g. lack of successor) may actually benefit the economic sustainability of that system over the longer term if it leads to farm consolidation. There is also potential for conflict between economic and environmental objectives as although more intensive production tends to generate less emissions on a unit product basis it still produces more emissions overall.

The overall analysis shows that dairy farms, followed by tillage farms, tend to be the most economically sustainable farm systems. The results reveal the wide variation in environmental performance along all of the dimensions measured. While it is evident that the intensive dairy systems produce more GHG emissions than other less intensive systems, the consistent pattern running through all of the farm systems is the correlation between economic performance and environmental sustainability. In relation to GHG emissions, the top economically performing farms tend to be the best performing farms on this aspect of environmental sustainability, in other words, they emit relatively less GHG's per unit of product produced. In this case, increases in efficiency and productivity generate increased profits, without negative environmental consequences. Herrero et al. (2013) refer to this as a "positive and simultaneously perverse impact" as farmers may be incentivised to increase herd size, rather than produce more with fewer, more productive animals. In relation to risk to water quality, the top performing economic farms tend to produce a greater nitrogen surplus. However the top performers economically produce more product (e.g. milk) per kg of N surplus. These intensive farmers may face the greatest challenge in expanding production without increasing the risk to water quality.

An interesting conclusion of this analysis is that moderately intensive systems (middle one-third in terms of gross margin) appear to be more sustainable than low intensive systems. This may call into question the traditional view that low intensity systems of production have the least negative impact on the environment. Given the need to increase food production it may be desirable to encourage low intensity production to become more intensive since this may improve both the environmental and economic sustainability of such systems, while also increasing their volume of output. This may include changing systems, for example from a dry-stock to a dairy system.

Dairy and tillage farms tend to be the most sustainable farms from a social perspective but the differences across systems are not as pronounced as for the economic indicators. Demography in particular tends to be correlated with economic performance, whereby the better performing farms from an economic perspective also tend to have a younger age profile. The adoption of innovative practices was also shown to be highly correlated with farm economic performance across all systems. Wider adoption of innovative practices which increase the efficiency of resource use (land, animals, nutrients, human capital and technology) have the potential for a "win-win" outcome by not only reducing the impact on the environment, but also reducing production costs.

As our understanding of the interactions between the intensity of farming, it's impact on the environment, and the role of innovation in this relationship deepens, new and more sophisticated indicators will be developed. Indicator development is an iterative process as, particularly in the area of environmental sustainability, the development of novel scientific methodologies will necessitate further data collection. As such, indicator design will evolve over time and will benefit from on-going validation and expert consultation. One of the greatest advantages of sustainability indicators is that they can be used to chart progress over time, however it is likely that this will necessitate the retrospective recalibration of indicators as additional data and more sophisticated methodologies become available. It is important to stress that the true value of sustainability indicators lies not in the interpretation of the absolute values in a given time period but in the evaluation of trends that are of concern to stakeholders generally and policy makers in particular. Indeed as environmental policy targets are set out, there will also be better insight into future policy analysis requirements. As the science and policies evolve, so too will the collection of data and the selection of indicators.

References

Breen, J., Donnellan, T. and Westhoff, P. (2010). 'Food for thought: EU climate change policy presents new challenges for agriculture', EuroChoices 9 (3), 24–9.

Buckley, C., Murphy, P., Wall., D., 2013. Farm-gate N and P balances and use efficiencies across specialist dairy farms in the Republic Ireland. *REDP Working Paper Series 13-WP-RE-02* Available: http://www.agresearch.teagasc.ie/rerc/downloads workingpapers/13wpre02.pdf

DAFF (2010). Food Harvest 2020, A vision for Irish-agri-food and fisheries. Department of Agriculture, Fisheries and Food, Dublin, Ireland.

Dillon, E. J., Hennessy, T., Buckley, C., Dillon, E., Donnellan, T., Hanrahan, K., Moran, B. and Ryan, M. (2014). The sustainable intensification of the Irish dairy sector. Paper prepared for presentation at the 88th Annual Conference of the Agricultural Economics Society, AgroParisTech, Paris, France.

Dillon, E.J., Hennessy, T., Hynes, S., Garnache, C. and Commins, V. (2007) Measuring the Sustianability of Irish Agriculture. Rural Economy Working Paper Series: 07-WP-RE-01. Teagasc.

Dillon, E.J., Hennessy, T. and Hynes, S. (2010) Assessing the sustainability of Irish Agriculture. *International Journal of Agricultural Sustainability* 8(3) 2010:131-147.

Donnellan, T. (2014) Climate change and the food chain. RIA Climate Change Sciences Committee. Issue 12 2014. Royal Irish Academy:Dublin.

EC (2012) Innovating for Sustainable Growth: A Bioeconomy for Europe. Communication form the Commission to the European Parliament, the Council, the European Economic and Social Committeed of the Regions. Innovating for Sustainable Growth: A Bioeconomy for Europe {SWD(2012) 11 final}

EPA (2009) AG-BIOTA – Monitoring, Functional Significance and Management for the Maintenance and Economic Utilisation of Biodiversity in the Intensively Farmed Landscape. *(2001-CD/B1-M1) STRIVE Report.*

EPA (2013) https://www.epa.ie/pubs/reports/air/airemissions/ Ire_GHG_Emissions_1990_2012_handout.pdf

Frater, P. and Franks, J. (2013) Measuring agricultural sustainability at the farm-level: A pragmatic approach. *International Journal of Agricultural Management*, Vol. 2, Issue 4.

FAO, (2003). Compendium of Agricultural – Environmental Indicators 1989-91 to 2000. Statistics Analysis Service, Statistics Division, Food and Agriculture Organisation of the United Nations, Rome (November, 2003).

FAO (2009). How to Feed the World in 2050. Food and Agriculture Organisation of the United Nations http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper /How_to_Feed_the_World_in_2050.pdf

Frawley, J., P. Commins, S. Scott and F. Trace (2000) Low Income Farm Households: Incidence, Characteristics and Policies. Combat Poverty Agency Research Series, Oak Tree Press, Dublin.

Gómez-Limón, J. A., Riesgo, L. (2009) Alternative approaches to the construction of a composite indicator of agricultural sustainability. An application to irrigated agriculture in the Duero basin in Spain. *Journal of Environmental Management*, 90, 3345-3362.

Gómez-Limón, J. A., Sanchez-Fernandez, G. (2010) Empirical evaluation of agricultural sustainability using composite indicators. *Ecological Economics*, 69, 1062-1075.

Government of Ireland (2012) Delivering our Green Potential. Government Policy Statement on growth and employment in the green economy. Government of Ireland.

Hennessy, T., Moran, B., Kinsella, A. and Quinlan, G. (2013a) Teagasc National Farm Survey Results 2012. Teagasc, Oak Park.

Hennessy, T., Buckley, C., Dillon, E., Donnellan, T., Hanrahan, K., Moran, B. and Ryan, M. (2013b). Measuring Farm Level Sustainability with the Teagasc National Farm Survey. Teagasc, Athenry, Co. Galway.

Herrero, M. and Thornton, P.K. (2013) Livestock and global change: emerging issues for sustainable food systems. Proceedings of the National Academy of Sciences of the United States of America. Vol. 110. No. 52.

Leeuwis, C. (2004) Communication for Rural Innovation: Rethinking Agricultural Extension. Oxford: Blackwell Science.

Leip, A., Weiss, F., Wassenaar, T., Perez, I., Fellmann, T., Loudjani, P., Tubiello, F., Grandgirard, D., Monni, S. and Biala, K., (2010). Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS): Final report. European Commission Joint Research Centre.

OECD and Eurostat (2005) Oslo Manual: The Measurement of Scientific and Technological Activities – Proposed Guidelines for Collecting and Interpreting Technological Innovation Data. *Joint publication: OECD and Eurostat*. Third Edition.

OECD (2008), Handbook on Constructing Composite Indicators: Methodology and User Guide. Organisation for Economic Co-operation and Development. Paris.

Reig-Martinez, E., Gómez-Limón, J. A., Picazo-Tadeo, A. J. (2011) Ranking farms with a composite indicator of sustainability. *Agricultural Economics*, 42(4), 2011.
Available : http://decigarrasyhormigas.files.wordpress.com/2013/01/artc3adculo-de-reig-martc3adnez-et-al-2011.pdf

Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001, 'Constructing a farm level indicator of sustainable agricultural practise', Ecological Economics 39, 463–478.

Schroder, J. J., Scholefield, D., Cabral, F. & Hofman, G., 2004. The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. *European Journal of Agronomy*, 7, 15-23.

UN (1987) Report of the World Commission on Environment and Development Our Common Future. United Nations.