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Measuring GHG Emissions Across the Agri-Food Sector Value Chain: The Development of a Bioeconomy Input-Output Model*

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ABSTRACT

Increasing food production to meet rising global demand while minimising negative environmental impacts such as agricultural greenhouse gas (GHG) emissions is one of the greatest challenges facing the agri-food sector. Sustainable food production relates not only to primary production, but also has wider value chain implications. An input-output (IO) model is a modelling framework which contains information on the flow of goods and services across a value chain at a regional or national economy level. This paper provides a detailed description of the development of a Bioeconomy IO (BIO) model which is disaggregated across the subs-sectors of the agri-food value chain and environmentally extended (EE) to examine environmental outputs, including GHG emissions, We focus on Ireland, where emissions from agriculture comprise 33% of national GHG emissions and where there has been a major expansion and transformation in agriculture supported by national and EU policy. In a substantial Annex to this paper, we describe the modelling assumptions made in developing the BIO model. Breaking up the value chain into components, we find that most value is generated at the processing stage of the value chain, with greater processing value in more sophisticated value chains such as dairy processing. On the other hand, emissions are in general highest in primary production, albeit emissions from purchased animal feed are higher for poultry than for other value chains, given the lower animal based emissions from poultry than from cows or sheep. The level of disaggregation also shows that the sub-sectors are themselves discrete value chains. The analysis highlights that emissions per unit of output are much higher for beef and sheep meat value chains than for pig and poultry. The analysis facilitated by the BIO model also allows for the mapping of emissions along the agri-food value chain using the adapted IO EE approach. Such analysis is valuable in identifying emissions 'hot-spots' along the value chains and analysing potential avenues for emission efficiencies.

Keywords: Bio-economic Input-Output; LCA, Agri-Food Value Chain; Disaggregation methodology

JEL codes: Q53, C67, Q10

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1 Introduction

The need to reduce the environmental footprint of food production in the face of global population growth and growing food demand is one of the grand challenges facing agricultural production and wider agri-food value chains (Robertson et al., 2005). There are many European examples of national initiatives to optimise natural resource use as a mechanism for sustainable intensification of agri-food production (e.g. the Origin Green sustainability initiative in Ireland), which include environmental measures of biodiversity, water and air quality. While biodiversity and water quality are localised issues, the effect of emissions to air is a global issue. The agricultural sector accounted for 10% of the EU's total greenhouse gas (GHG)[2] emissions in 2015 (Eurostat, 2018), however, due to the global nature of agri-food markets, emissions in relation to the production of specific agri-food goods, can arise not only inside the farm-gate or within national boundaries, but along the complexity of the value chain that leads from producer through processors and marketing intermediaries to the final consumer of the good. In many cases, much of the environmental footprint of specific goods lies in the purchases, materials and services required for production (Berners-Lee, 2011).

There is a considerable literature that addresses emissions generated by different production sectors (see for example Hendrickson et al., 2006; Weber et al., 2008). Assessment of GHG emissions along the entire value chain in order to address possible inefficiencies has become a well-recognised technique for developing policies associated with environmental management (Clift, 2000). In relation to the agri-food sector, GHG emissions generated in production processes have received considerable attention in relation to individual products (Del Borghi et al., 2014; Sonesson et al., 2016; Palmieri et al., 2017) as well as collectively (Mylan et al., 2015), at sectoral or sub-sector level or as a regional/global supply chain (MacLeod et al., 2017; Porter et al., 2016; Mottet et al., 2017; Camanzi et al., 2017). However, agri-food production involves multiple, often inter-linking sub-sectors which may have differential efficiencies and inputs, with consequently different emission footprints. For example, processed foods may include components from meat, dairy and grain value chains, which in turn will have inputs from animal feed, fertiliser and pesticide value chains. These inputs can derive from multiple countries, while the individual sub-sectors involved are often subject to specific regulations (e.g. Nitrate Directive restrictions on inputs to dairy farms in EU).

In a world where agriculture needs to become more efficient in relation to emissions as well as costs, it is reasonable to expect that sub-sectors with greater emission efficiencies may have a comparative advantage in future policy and emission reduction debates. The achievement of increasing food production while complying with environmental regulation and consumer demands, requires an assessment of emissions both across and within agri-food value chains. This would allow for the identification of the sub-sectors where emissions per unit of value are the highest/lowest, with a view to assessing where environmental damage is compensated the least/most. However, the complexity of the within and between sector interactions in agri-food value chains presents data and methodological challenges.

In quantifying emissions along agri-food value chains, Ireland presents an interesting case study. Ireland has a target to achieve a 20% reduction of non-Emission Trading Scheme (non-ETS) emissions (i.e. agriculture, transport, the built environment, waste and non-energy intensive industry) on 2005 levels, by 2020. As a result of the high share of ruminants (dairy and beef animals) in Irish agriculture[3], the sector is responsible for approximately one third of non-ETS emissions (32.3% in 2016) (EPA, 2017). However, a European Commission report showed that the Irish grass-based production model 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). Largely on foot of the marketing of these sustainability credentials, Ireland has gained a reputation as a producer of high quality food and drink for global markets (FutureInFood, 2017) with exports in excess of 75% of its total agricultural output. However, Ireland has targets to significantly expand agricultural production for the dairy and beef sectors (DAFM, 2015), which is already leading to an increase in annual emissions. The achievement of sustainable intensification will thus require an assessment of emissions along the value chain to optimise expansion in sectors with the greatest environmental and economic comparative advantage.

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[2] The primary greenhouse gases in Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone.

[3] Ruminant agriculture is more emissions intensive than other forms of agriculture. These emissions consist of methane (CH_4) which is generated as a by-product of the natural ruminant digestive process (enteric fermentation), and nitrous oxide (N_2O which is generated from both animal waste and from the use of nitrogen fertilisers (Ryan et al., 2016)

There is a large literature on accounting and modelling methodologies that describe many facets of agri-food production processes including GHG emissions. For example, Hynes et al. (2009) employed spatial micro-simulation modelling techniques to examine methane emissions across Irish farms. The results of the modelling process indicated that there would be significant regional variation in the burden of an agricultural tax based on methane emissions. Elsewhere, the FAPRI-Ireland model, as applied by the Irish EPA (EPA, 2017) to model agricultural emissions, is a dynamic, partial equilibrium model which is linked to both to the FAPRI-EU and world modelling systems. This framework has been used extensively in the analysis of agricultural and trade policy changes (Binfield et al., 2001; 2008; 2009) and is increasingly used to estimate the associated impacts on GHG emissions. These models can be characterised as agricultural policy studies that estimate the impact of varying policy stimuli on economic outcomes: income, output, inputs, etc. (either at the farm level or aggregate sectoral level), which are subsequently used to calculate associated emissions from agricultural activity data. Emissions analysis is performed in the context of estimating emissions under various economic policy scenarios relative to binding climate change policy and the achievement of non-ETS emissions reductions targets for Ireland as set out in the EU Effort Sharing Decision (ESD). However, single sector models such as the FAPRI model, while containing great detail of global markets, do not capture the interplay, flows and connections between different sectors (Meyers et al., 2010).

The emissions accounting procedures of the Intergovernmental Panel on Climate Change (IPCC, 2006) provide a consistent methodology in these studies for the purpose of estimating national emissions under policy change scenarios, which are comparable to a baseline from the country's National Inventory Report (Duffy et al., 2017) and against specific emissions reduction targets into the future as detailed in the ESD. A significant drawback to the IPCC methodology, however, is that it seeks to accomplish an international objective of reducing global emissions, but is limited by its national boundary reference. Accordingly, the IPCC methodology only captures emissions originating or emitted within national boundaries and thus does not identify the global emissions associated with a product or production process. Furthermore, by dividing emissions into sectoral categories to provide a consistent approach comparable across countries, it does not capture the complexity and integrated nature of agricultural production systems within the rest of the economy. This results in emissions from upstream manufacture of agricultural inputs, fuel use and land use change, being attributed to alternative sectors of the economy, or excluded altogether in the case of imported feed and fertiliser produced outside the national boundary (Schulte et al., 2011). Therefore, this approach cannot accurately identify the most carbon efficient product or production process in a set of alternatives.

Life cycle analysis (LCA) provides an alternative approach to assess and evaluate the environmental impacts of products or processes over their full life span (or within the bounded limits of a product supply chain as defined by the system boundary) (Matthews et al., 2015). Where the IPCC inventory represents an output-based accounting system, LCA on the other hand is a bottom-up input-based methodology focusing on specific production processes (Pairotti et al., 2015). As a result, there is a growing number of LCA whole farm systems models, which propose LCA as a suitable method for emissions analysis and which highlight the relative deficiencies of the IPCC method when analysing emissions efficiency of alternative production processes (Casey et al., 2006; Crosson et al., 2011; O'Brien et al., 2012; Foley et al., 2011; O'Brien et al., 2014; Geraghty, 2011; O'Brien et al., 2012) found that the IPCC methodology incorrectly ranked the Irish confinement-based dairy production system as more carbon efficient per unit of product (milk) because it excluded embedded or indirect GHG emissions from upstream input processes. The LCA method on the other hand takes account of emissions from the entire supply chain (up to the farm gate) and results indicate that LCA provides a more appropriate holistic accounting approach for the analysis and development of farming systems which target a net reduction in global GHG emissions.

Similarly, Schulte et al. (2011) highlight that while total emissions per unit area for the pasture-based dairy sector as measured by the National Inventory Reports is high, emissions per unit output, as measured by LCA, are the lowest in the EU (Leip et al., 2010). Thus, strategies aimed at reducing Irish emissions through reductions in Irish production levels have the potential to indirectly increase emissions efficient production elsewhere. This may ultimately raise global emissions if less efficient production fills the gap left in international demand. This concept is referred to as 'carbon leakage', which arises directly as a result of the metrics employed internationally for the national GHG inventories under the Kyoto Protocol and according to the IPCC method.

LCAs as applied to Irish agricultural production, are typically defined as process-based 'cradle to farm gate' studies, which in addition to measuring farm level production activities, capture the emissions arising from up-stream processes involved in the delivery and production of inputs, including imported feed and fertiliser. These 'process' or 'product' based LCAs can therefore be used to calculate emissions beyond the national boundary arising from a specified activity or process. LCA allows for the comprehensive evaluation of alternative measures and/or changes to the production cycle which result in either reduced overall emissions or lower emissions per unit output. Accordingly, whole farm system LCAs are increasingly presented as appropriate tools to develop and measure GHG mitigation strategies for livestock farms. Typically, these analyses focus on a specific process or potion of a value chain (Casey and Holden, 2005, 2006; O'Brien et al., 2011; Crosson et al., 2011; Foley et al., 2011; O'Brien et al., 2014), while Geraghty (2011) and Finnegan et al. (2017) focus specifically on the processing of Irish dairy products. Although informative, such process-based LCAs are of limited value to policy-making or integrated, economic and environmental impact assessment at national economy scale. Furthermore, LCA analysis suffers from truncation error, whereby limitations set by the boundary specification result in analysis that fails to fully capture the emissions of upstream processes in their entirety (Crawford, 2008; Lenzen, 2000; Suh et al., 2004).

An alternative approach which addresses the limitations of both LCA and IPCC methodologies, is proposed here in the form of an Input-Output Life Cycle Assessment (IO-LCA). The input–output based LCA approach uses economic transaction tables and national environmental accounts to determine the economy-wide environmental and economic impact, triggered by shocks to final demand in the disaggregated agriculture sector. Thus, while process based LCAs can provide analysis of the impact of production or mitigation technologies at the farm level, input-output based LCA can offer sustainability guidance at the national scale, while also integrating assessment of the accompanying economic impacts. According to Munksgaard (2001), IO-LCA is a powerful accounting tool for examining the structure of economic activity and associated issues such as the pollution and/or resource use embodied directly or indirectly, in the production, consumption and trade flows under different accounting principles.

While there is a substantial literature employing process based LCA and IO-LCA research, there are few studies which analyse sub-sectoral emissions within the agri-food value chain. Notable exceptions which have adopted an IO–LCA approach to study specific agri-food value chains, include Yan et al. (2013) and West & Marland (2002), who developed an IO-based LCA model to evaluate GHG emissions in pasture-based milk production in Ireland and tillage systems in the USA respectively, or Virtanen et al (2011) who used an IO approach to consider the emissions associated with different lunch portions. Furthermore, these analyses have not incorporated emissions embedded in imported goods and services into the IO table, nor have they been disaggregated to include the wider agri-food sector. This is possibly due to the complexity of the disaggregation involved in individually examining the allocation of inputs and outputs for agri-food sub-sectors such as dairy and beef production. However, this level of disaggregation is necessary to gain a greater understanding of the environmental sustainability of agricultural commodities across agri-food value chains.

This paper fills a gap in the literature by describing the development of a disaggregated agri-food bio-economy IO (BIO) model in order to identify indirect suppliers and thus indirect emissions associated with final agri-food products. The model is extended to examine between and within-sector differential emissions across the Irish agri-food value chain. The IO LCA approach applied in this study allocates emissions to different sectors taking account of the structure of the macroeconomy. This approach has the benefit of not underestimating global figures and thus avoiding truncation evident in process based LCA, whilst being less data intensive. At the same time this approach has a number of well recognised limitations, including the time lag in data availability associated with the publication of national accounts and the fact that the calculations are made for economic sectors and not for certain products. Thus even disaggregated input-output tables as developed in this analysis, combine products and production technologies that are heterogeneous in terms of input requirement and environmental output production, leading to the issue of 'aggregation error' (Suh et al., 2004). This approach thus results in IO-LCA calculations which are more comprehensive than process based LCA on the one-hand and cruder on the other hand (Pairotti et al., 2015). While there are strengths and weaknesses to both approaches and there is an on-going debate in the literature on the merits of their various applications (Gibon et al., 2017; Lenzen, 2000; Pomponi et al., 2018; Schaubroeck et al., 2017; Yang, 2017a, 2017b; Yang et al., 2017), given data limitations and the macroeconomic focus of this investigation, an IO-LCA approach is deemed most appropriate.

The rest of this paper is structured as follows. The next section describes the theory of value chains and the context of the Irish agri-food value chain. The methodology and data sections describe the sectoral disaggregation of the agri-food sector and the assignment of emissions in the development of the LCA Bioeconomy IO 'BIO' model. The results section presents the structure and associated emissions of the different components of the agri-food value chain. The paper concludes with policy recommendations, analytical caveats and suggestions for future research in this area. An Annex containing the detail of the agri-food inter- and within-sector BIO disaggregation is also provided to allow for replication of the model using Farm Accountancy Data Network (FADN) data.

2 Value Chain Analysis

Theory of Global Value Chains and Irish Policy Context

Gereffi & Lee (2012) traced the emergence of global value chains (GVC) to the 1960s when globalisation elevated competition between firms from the local to the international stage, leading to a change in production methods, as firms looked for ways to reduce production costs by outsourcing different segments of the production process overseas. By using global value chains to gain competitive advantage, a country can improve income, employment, and productivity (OECD, 2013). For example, the Irish dairy value chain has previously been mapped and analysed by Heery et al., (2016). The authors found that the sector is relatively fragmented and optimisation at farm and processing levels is necessary to retain competitive advantage. According to their findings, the over-reliance of the Irish dairy system on basic commodity sales is a threat to the sector in the absence of scale and cost advantages. For the Irish agri-food sector to be in a position to capitalise on the projected increase in global demand for food, the challenges presented by both the production process and the value chain need to be addressed.

The GVC approach assists in understanding and mapping the agri-food sector structure through providing insights as to the information necessary to populate an IO model. There are four basic elements within the GVC methodology: input-output structure, geographical scope, governance structure and institutional context. In the agri-food value chain context, the GVC methodology allows us to understand questions such as:

- How can policy makers support the creation of employment, wealth and innovation amid increasing global competition?
- In which areas of the agri-food value chain are emissions concentrated?
- Which sub-sectors can generate the greatest economic and emissions efficiencies?
- How can policy makers ensure that the benefits of investment in the agri-food sector, such as jobs, added value and innovation accrue to the domestic economy?
- What are the regulatory barriers to the development of the sector?

The agri-food sectoral strategy Food Wise 2025 (DAFM, 2015) sets ambitious targets for the Irish agri-food sector to increase exports by 85%, relevant primary production by 65% and value added by 70%, with a target of 50% expansion in production envisaged for the dairy sector. However this presents environmental challenges as over the same period, Ireland has committed to reduce GHGs by over 20% (EPA, 2015). In addition, since the removal of milk quotas in 2015, there has been an increase in dairy cow numbers with a consequent increase (41%) in dairy beef meat (and a reduction (4%) in meat from other beef animals) as illustrated in Table 1. As Irish dairy systems are in general more efficient than beef systems in relation to GHG emissions per unit of product (Hennessy et al., 2013) and because Irish dairy is comparatively more efficient relative to international competitors (Leip et al., 2010), this shift to dairy beef needs to be investigated in relation to a potential shift of emissions within the agri-food sector value chain. In a world where agriculture needs to be more environmentally efficient, there may be an argument for prioritising the most efficient systems under the Common Agricultural Policy.

Value Chain Emissions Accounting

Under the United Nations Framework Convention on Climate Change (UNFCCC), countries are legally obliged to report national GHG inventories annually. The EPA in Ireland estimates emissions using IPCC methodologies and the Common Reporting Format (CRF) software, to prepare annual National Inventory Reports (NIR) (Duffy et al., 2017). The CRF is a set of spreadsheets containing tables reporting emissions and background data for various sectors, while the NIR describes the methodologies, data sources, background information and the entire process of inventory compilation (Duffy et al., 2017).

Table 1.
Growth in Agri-Food Volume 2012-2017 (Ratio 2017-2012)

	2012-2017 Growth Ratio
Beef and veal	1.23
Pig meat	1.13
Sheep meat	1.13
Poultry meat	1.11
Other meat	1.00
Seafood Processing	1.06
Dairy Products	1.39
Dairy Cows	1.26
Suckler Cows	0.94
Dairy Beef Meat*	1.41
Beef Meat*	0.96
Share of Beef from Dairy*	1.23

Source: Central Statistics Office (www.cso.ie)
*2012-2020

The IPCC territorial (or production-based) approach to emissions accounting is widely used for national emissions accounting but is also criticised (Schulte & Donnellan, 2012; Peters & Hertwich, 2008) as it does not account for emissions embodied in international trade and transportation and exacerbates the process of carbon leakage (Schulte & Donnellan, 2012). The territorial approach to emissions accounting is incomplete as it does not capture all emissions along the value chain. The alternative method is a consumption-based LCA approach to emissions accounting, which incorporates emissions associated with final domestic consumption as well as associated imports (Boitier, 2012).

Given the complexity of inter-sectoral and within-sector linkages, IO-LCA analysis is a powerful accounting tool for examining the structure of economic activity and associated issues such as the pollution and/or resource-use embodied directly or indirectly, in the production, consumption and trade flows under different accounting principles (Munksgaard, 2001). IO analysis allows the magnitude of backward and forward linkages between a sector and the suppliers of its inputs and users of its outputs to be evaluated (Acquaye et al., 2011a 2011b; Puttanpong et al., 2015), as well as allowing for the decomposition of the Leontief[4] multiplier into direct and indirect paths using Structural Path Analysis (SPA) (Puttanpong et al., 2015; Yang et al., 2015). IO-LCA has thus become an increasingly commonly used technique to measure and allocate responsibility for emissions (Puttanpong et al., 2015; Turner et al., 2009; Yang et al., 2015). In addition, the use of Environmentally Extended (EE) IO further allows for the capture of inter-relationships between sectors in the economy and the tracking of emissions which are embodied in raw materials, intermediate and final products, from sector to sector (Kitzes, 2013).

This paper chronicles the development of the BIO model to create an EE IO model and calculate direct and indirect emissions along the value chain. The IPCC country-specific emissions from energy and production processes are augmented by emissions associated with imports and exports. In addition, IO-LCA is used to assess the magnitude of emissions to identify if there are emissions 'hot spots' along the agri-food value chain.

3 Methodology: Bio-Economy Input Output Model

The first step in undertaking a value chain analysis of the agri-food sector requires the disaggregation of the IO tables generated every five years by the Central Statistics Office (CSO) in Ireland. However, the national IO tables describe the flows between just two agri-food sectors: Agriculture and Forestry & Fisheries (AFF). In this section we describe the development of a disaggregated (42 sector Agri-Food) and (33 sector Energy) BIO Model.

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[4] Wassily Leontief (1906–1999) is credited with developing this type of analysis and earned the Nobel Prize in Economics for its development.

This work builds on earlier agri-food IO models (O'Toole and Matthews, 2002; Miller et al. 2009; Grealis et al., 2017) and extends their work to include:

- the adaptation of the most recent (2010) CSO IO Model for Ireland
- the expansion of the agricultural sectors, making them more consistent with the accounting flows and characteristics of the Teagasc National Farm Survey (NFS) and more broadly the EU Farm Accountancy Data Network (FADN)
- systematisation of the development of the model to facilitate replication.

The IO approach is a linear modelling framework that was first developed by Leontief in the 1930s (Hendrickson et al., 1998; Lave et al., 1995). Production in an economy is described as a cyclical system in which inputs are used to produce outputs, which in turn can be used as inputs to other processing systems. These help to analyse interdependencies that exist in an economy and trace input requirements through a product life cycle (Grealis & O'Donoghue, 2015).

Inputs to the production cycle come from imports, labour and capital. However, firms also use outputs of other firms – intermediate consumption – as inputs to their production. Outputs are designated to exports and final demand represented by households, governments and non-profit organisations. Such a framework is useful in analysing knock-on effects of changes in demand, output, employment, gross value added (GVA) and household income (Grealis & O'Donoghue, 2015). In the context of policy decision-making in relation to the allocation of limited economic resources, such analysis enables the targeting of investments where combined benefits are the greatest.

The mathematical structure of IO consists of a set of linear equations. The IO system can be written as in Equation 1, where *a* represents a technical coefficients matrix, *x* is a vector of total outputs of the sectors, *f* is a vector that represents the exogenous final demand and *ax* denotes intermediate demand (Joshi, 2000). Equation 1 can be re-written as a vector of the sectoral outputs needed to accommodate changes in exogenous demand as in Equation 2 and known as Leontief's inverse (Hendrickson et al., 1998; Joshi, 2000; Lave et al., 1995).

$$x - ax = f \qquad (1)$$

$$x - [I - a]^{-1} f \qquad (1)$$

The first step in model creation involves the disaggregation of sectors into sub-sectors namely Agriculture, Forestry, Fisheries, Aquaculture, and the Food Processing and Fuel sectors. The most disaggregated data available was used in this step. Where data are limited, shares based on output are applied, assuming the same cost function per sector. Given that the CSO IO table is balanced, the new table also needs to be balanced, keeping the totals constant. While there are a variety of ways of doing this such as general entropy or the RAS approach (UN, 1999), we take a relatively conservative manual balancing approach, based on expert judgement.

Environmentally Extended Hybrid Input-Output Model

Once disaggregated, the BIO model was adapted to develop a hybrid IO LCA model (a combination of EE IO and Process LCA) to analyse emissions embedded in the agri-food value chain in Ireland. A similar approach was previously described by Munksgaard (2001) who used a hybrid IO LCA model to analyse consumption of foods produced in Denmark. The model process adapted for analysis of emissions associated with the Irish agri-food sector is depicted in Figure 1. The IO framework can be extended for environmental analysis by multiplying *x* by the matrix of environmental burden coefficients *r* (the ratio of environmental burdens to output for each sector) to find a vector of total environmental burdens associated with final demand, denoted *e* (Kitzes, 2013).

$$e = rx = r[I - a]^{-1} f \qquad (3)$$

The *r* matrix can include environmental coefficients of any environmental impacts of interest such as energy use and GHG emissions (Joshi, 2000). In this analysis, the environmental burden coefficients per million euros of output, expressed as Carbon dioxide equivalents (CO_2eq.), include emissions from energy consumption as well as process emissions (e.g. animal and soil emissions from agriculture).

The *e* matrix captures both direct and indirect (or total) emissions that originate from sales to final consumers (Kitzes, 2013). Direct emissions arise as a result of activities directly related to production (rI). Indirect emissions are associated with direct and indirect suppliers and are the difference between direct and total emissions (Acquaye & Duffy, 2010).

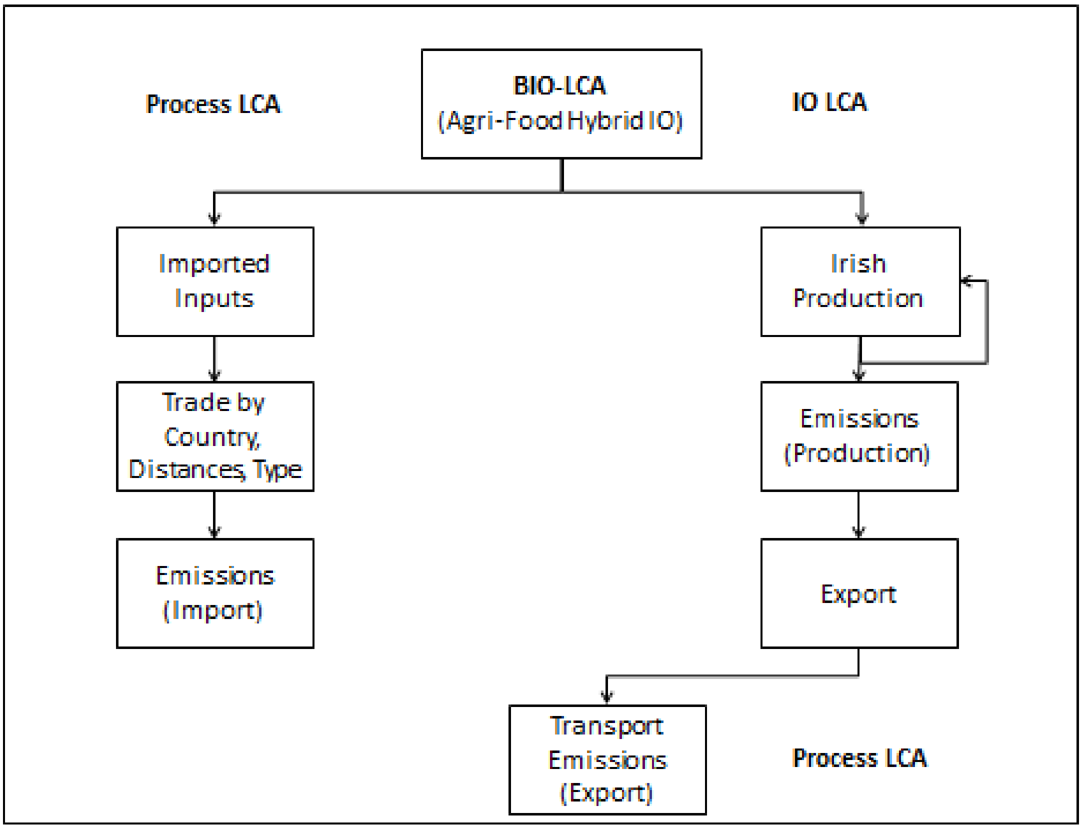

Figure 1.BIO Model Process
Source: Adapted from Munksgaard (2001).

Estimating Emissions from Agriculture[5]

Livestock

Emissions from agricultural livestock (sheep, cattle, horses, pigs, poultry, deer and goats) are calculated using the methodology outlined in the NIR (Duffy, 2017) and described in IPCC (2006). Emissions factors and animal stock inventories, as reported in the CRF tables (UNFCCC, 2003:13) of the NIR (Duffy et al., 2017) and in line with the CSO livestock survey (CSO, 2017), are used to calculate aggregate livestock (sectoral) emission factors per million euro of output. Emissions factors are applied to the outputs from IO sectoral tables to describe associated emissions flows. In this case, all emissions associated with animal activities are calculated for 2010, such that the sum of emissions for the livestock sectors matches the figures reported in the CRF tables accompanying the NIR.

There are a number of environmental impacts that can be accounted for in the LCA including air pollution, water pollution, waste, consumption of resources, etc. In this analysis, only air pollution impacts with Global Warming Potential (GWP) e.g. Carbon dioxide (CO_2), Nitrous oxide (N_2O) and Methane (CH_4) emissions are considered. The details of the calculation methodology and data requirements are presented in Appendix 1 of the BIO Annex.

In the case of CH_4, emissions are calculated by multiplying aggregate emissions factors per unit livestock by annual livestock population records from the CSO (2017), i.e. CH_4 emissions combine the emissions factors for enteric fermentation and manure management from the NIR (Duffy et al., 2017).

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[5] Note there are no additional emissions from seafood as fish do not produce methane. The only emissions are derived from inputs such as energy use and fertiliser used for land based feeds.

As with CH_4 emissions, a total N_2O emissions factor for each livestock (sector) is calculated by summing derived direct emissions factors (from manure management and fertiliser application to managed soils) and indirect emissions factors (from manure management and dung and urine deposition). The emissions factors are then converted to express emissions in kilotonnes, per million euro of output (kt N_2O/ €m). The emission outputs from the livestock sectors in terms of N_2O and CH_4 emissions are subsequently calculated by multiplying the economic output for each product stage/livestock sector in the IO tables, by the environmental impacts per million euro of output, as measured by derived emissions factors for N_2O and CH_4 (Table 2).

Table 2.

Methane and Nitrous Oxide emission factors for livestock per unit of output value

	Kt CH_4 /€m	Kt N_2O /€m
Dairy	0.081	0.0011
Cattle	0.168	0.0059
Sheep	0.162	0.0031
Horses	0.014	0.0015
Pigs	0.028	0.0017
Poultry	0.017	0.0014
Deer and Goats	0.004	0.0005

Feed

An LCA approach is applied to farm level data from the Teagasc National Farm Survey (NFS)[6] to calculate the emission factors associated with growing key crops on Irish farms. These include concentrates (wheat, barley & oats), pasture, winter forage, silage, hay and root crops. The Teagasc NFS collects associated sales price and input cost data, which, along with production data on input use and output yield, enables the calculation of emissions per unit value of crop. Once the economic output for each product stage (disaggregated agriculture sector) is calculated, a vector of environmental outputs can be obtained by multiplying the economic output at each stage by the environmental impact per euro of output (Hendrickson et al., 2006).

A crops sub-model was developed to calculate the input, resources use and emissions associated with the full range of crops grown, processed and fed to livestock. This enables the calculation of emissions from upstream input production (e.g. CO_2 emissions from the production of diesel, fertiliser, pesticides, etc.) and the emissions associated with their subsequent transformation through on-farm processes (e.g. N_2O emissions from the interaction of fertiliser applications with soils and CO_2 emissions from on-farm combustion of fuel used for machinery operation). The *e* matrix (Equation 3) captures both these direct and indirect (or total) emissions that originate from sales to final consumers (Kitzes, 2013). Direct emissions are released as a result of activities directly related to production (rI). Indirect emissions are associated with direct and indirect suppliers and are the difference between direct and total emissions (Acquaye & Duffy, 2010). The emissions associated with each individual crop (include burdens associated with relevant inputs fuel, fertiliser, lime etc.) are summed and the average total emissions factor per unit value of crop derived and presented in Table 3.

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[6] see Data section for further detail

Table 3.

Carbon Dioxide emission factors for feed crops per unit of output value

Feed type	Crops kt CO_2 /€m
Concentrate Own Produced	1.69
Concentrate Opening Balance	1.69
Pasture	8.11
Winter Forage	4.11
Winter Forage Opening Balance	4.11
Winter Forage Purchases	1.49
Silage Own Produced	3.04
Hay Own Produced	3.94
Silage Opening Balance	3.04
Hay Opening Balance	3.94
Root crops	2.15

Estimating Emissions from Energy

While GHG emissions are usually presented in line with UNFCCC accounting rules and IPCC reporting guidelines, these do not readily capture changes in fuel and the sectoral mix of energy use, both upstream (e.g. emissions associated with the combustion of fossil fuels in electricity production that is subsequently used by consumers) and downstream (e.g. combustion of fossil fuels such as natural gas and coal). Using energy balance and cost data from the Sustainable Energy Authority of Ireland (SEAI, 2010, 2016) we address this issue by examining the energy sources being consumed across sectors and the upstream sources of that same energy and consequent emissions.

A detailed analysis of energy flows requires a much greater disaggregation of the energy sector than is commonly undertaken. Therefore, production sectors which produce primary energy (coal, lignite, crude oil) or transform it into secondary energy (coke, petroleum products, electricity, produced gas, steam and warm water) are listed individually. The resultant energy balances are detailed material inputs (e.g., coal and crude oil extracted) and intermediate energy inputs, which are transformed into secondary energy sources or consumed (combusted). From the energy balances, the transformation or combustion of energy can be calculated in terms of 'residual outputs' (unwanted polluting by-products), in this case GHG emissions.

SEAI published data were sourced to provide energy emissions factors (EF) for the range of fuel/energy sources on a tera joule basis, enabling the subsequent calculation of GHG emissions (CO_2 equivalents) throughout the entire supply chain. The methodology for calculating energy flows is in line with Beutel (1983) where the IO table is extended to enable the estimation of emissions associated with the direct and indirect energy content of products.

Estimating Emissions from Transporting, Imports and Exports

Depending on data availability, there are three methods of calculating emissions from transportation:

- fuel-based method, based on the amount of fuel consumed
- distance-based method, based on the mass, distance, and mode of each shipment and appropriate mass-distance emission factors for the vehicle used
- expenditure-based method, based on the amount of money spent on each mode of transport and secondary IO emission factors (Protocol, 2013).

The fuel-based method is used when data for fuel use from transport providers from vehicle fleets (e.g. trucks, trains, planes, vessels) can be obtained. In calculating CO_2 emissions, the fuel-based method is more accurate than other methods, because fuel consumption is directly related to emissions. However, the data requirements for this method are high. If the fuel-based method and distance method cannot be applied (e.g. due to data limitations), the expenditure-based method to calculate the emissions from transportation can be adopted, whereby the amount spent on transportation by type (V) is multiplied by the relevant factor from the IO table expressed as CO_2/€ (EF_{IO}) (Equation 4). The expenditure-based method is effective for screening purposes, however it has high levels of uncertainty and the fuel-based and distance-based methods are recommended for accounting for transportation emissions.

$$CO_2 = V \times EF_{IO} \qquad (4)$$

In the distance-based method, distance is multiplied by mass or volume of goods transported and relevant emission factors that incorporate average fuel consumption, average utilization, average size and mass or volume of goods and vehicles, and their associated GHG emissions, as in Equation 5, where d is distance travelled by m's mode of transport, T is weight of goods and EF_m is a mode-specific emissions factor. Accuracy is generally lower than the fuel-based method as assumptions are made about the average fuel consumption, mass or volume of goods, and loading of vehicles (Protocol, 2013).

$$CO_2 = \sum_m^N d \times T \times EF_m \tag{5}$$

In this analysis the distance-based method (Equation 5) was applied to estimate a weighted-average emission factor per euro of import (Equation 6), where CO_2 is total emissions (weighted by distance, mode of transport and weight) and IV is total import value (millions of euro). This factor is then applied to the value of imports (reported as part of BIO) to calculate transport emissions from imported inputs.

$$EF_{transp} = CO_2/IV \tag{6}$$

Estimating Emissions from Imports

It was assumed that imports are made with domestic technologies. This approach is popular as it assumes that the same emissions intensities are imbedded in import sectors as in domestic industries, allowing a domestic emissions vector to be applied to imports data (Andrew et al., 2009; Tukker et al., 2013).

4 Data

This analysis utilises a range of datasets for primary and secondary food sources including CSO National Accounts, Teagasc NFS, CSO Census of Industrial Production, SEAI, IPCC and space data, e.g. EPA data.

Primary Food Sectors

In the 2010 CSO IO Table, primary production is grouped into Agriculture, Forestry and Fisheries (AFF). We disaggregate these into agricultural livestock and crop sub-sectors, Sea fishing and Aquaculture and Forestry. In the following sections we describe the further disaggregation of the Agriculture and Forestry sectors. The disaggregation of the Sea fishing and Aquaculture sector is described in detail in Grealis & O'Donoghue (2015).

Agricultural livestock and crop data

The main source of data for the agricultural sector is the Teagasc NFS, which has collected farm-level data for over 40 years for the EU FADN, for the main land based agricultural systems, (with partial information for the pig and poultry sectors) on about 1000 farms annually. The NFS decomposes inputs and outputs at the enterprise level as Irish agriculture contains mainly pastoral animal systems, where farms may have at least one animal enterprise, together with enterprises that produce animal feed. Systems that are 'mainly dairy' may contain both a dairy enterprise and a cattle enterprise for non-milking animals. The beef industry is a very important sector in Ireland, with about 90% of farms in the NFS rearing beef cattle. Many tillage-only farms have multiple crop enterprises. In this model, this information is utilised to track inputs and outputs. Appendix 2 of the BIO Annex provides details of the methodology and data requirements for calculation of emissions from feed crops.

Appendix 3 of the BIO Annex contains the detail of the structure of the NFS data and how emissions are allocated to different sub-sectors within the agri-food value chain (using NFS data), along with a description of the preparation of the agricultural inputs and outputs and the consistency of outputs with the National Accounts (Table 18). Appendix 3 also presents the disaggregation of feed into sub-components, the allocation of output by final use and the sources of input into the AFF sector, along with animal inputs and crop outputs.

Forestry

The forestry component of the model is based on earlier work to develop an Irish IO Forestry Model (see Ní Dhubháin, 2009). This analysis utilises the same coefficients for the forestry sector (described in Table 4), using expert judgement to disaggregate. A comprehensive forest industry economic survey would be required to further improve the structure of the IO model for the forestry primary and processing sectors.

Table 4.
Distribution of Output by Source of Input in Forestry

	Share of Output
Intermediate Consumption	0.21
Wages and Salaries	0.21
Profits	0.28
Other Domestic Inputs	0.03
Imports	0.26
Total	1.00

Secondary Food Sectors

The 'Food & beverages and tobacco products' sector is disaggregated using the Census of Industrial Production (CIP), which provides turnover, output, labour and cost information for the following sectors:

- Processing and preserving of meat and production of meat products (disaggregated further with industry data into individual meat sectors)
- Processing and preserving of fish, crustaceans and molluscs
- Processing and preserving of fruit and vegetables
- Manufacture of vegetable and animal oils and fats
- Manufacture of dairy products
- Manufacture of grain mill products, starches and starch products
- Manufacture of bakery and farinaceous products
- Manufacture of other food products
- Manufacture of prepared animal feeds
- Manufacture of beverages
- Manufacture of tobacco products.

Inputs

The CSO IO table contains more disaggregated information in relation to costs than the CIP which contains information on Materials and fuels, Industrial Services and Non-industrial Services. In the accompanying Annex we report the detailed disaggregation of (a) the food and beverages sector into sub sector components, (b) the agriculture and fisheries inputs into the processing sector and (c) the food to food primary flows and the destinations of flows from the food processing sectors. In Appendix 4 (BIO Annex Tables 21 and 22), total food and beverages are disaggregated into sub-sector components at the domestic level. Imports for intermediate use are subtracted (Imports less Goods for Resale) to get domestic output. In the IO model, the three input components are further disaggregated using the same ratios as at the total sector level.

Utilising data consistent with the primary food sectors in Table 23, the agriculture and fisheries inputs into the processing sector are reported, while the food sector to food sector primary flows are reported in Table 24. Without further information, it is assumed that this is diagonal with inputs from the same sector and without any inter-sub-sector flows. While this is a relatively strong assumption, it will have relatively minor qualitative impact upon the overall multipliers. Table 25 describes the destinations of flows from the food processing sectors.

Energy Data

In order to disaggregate the energy sectors (Mining, Quarrying and extraction, Petroleum; Furniture; Other manufacturing, Electricity and gas supply), totals and energy flows in the SEAI Energy Balance Statistics (2016(are utilised. Other than the differential fuel inputs, there are no further data available on inputs, so existing shares from the SEAI data are assumed and applied to these IO Headings. Emissions from the Energy sector are taken from the EPA's common reporting format data files.

Data Validation

When utilising data from different sources, there is no guarantee that estimates will be comparable. While the SEAI Energy Balance statistics contain only volumes, monetary flows utilising industry and consumer prices for individual goods are derived utilising SEAI fuel prices. Table 5 compares total expenditures by sector on energy, utilising the SEAI and the IO table databases. Overall use is about 11% higher in the IO, with domestic demand being almost identical. Inter-industry differences are 16%, but this masks some variability across sectors. Differences of this order are not unusual when comparing different data sources.

Table 5.
SEAI Energy Balance versus IO Expenditures

	SEAI Energy Balance	IO	IO (Inter)	IO	IO (Inter)
	€m			Ratio relative to SEAI	
Industry & Transformation	4663	6544	5809	1.40	1.25
Transport, Commercial and Public	4332	3947	2528	0.91	0.58
Agri & Fisheries	374	385	385	1.03	1.03
Inter-Industry	9369	10876	8721	1.16	0.93
Domestic Final Demand	4824	4841	4841	1.00	1.00
Total Output	14193	15716	13562	1.11	0.96

In this analysis the IPCC country-specific emission factors compiled by the EPA and reported by the CSO are augmented by emissions associated with transportation of imported inputs as an extension of the IPCC's production-based method. Table 6 provides a similar validation comparing GHG emissions from our BIO-LCA analysis with similar emissions published by the EPA.

Table 6.
Comparing Carbon dioxide Emissions in Input-Output Table and Adjusted EPA Carbon Emissions

	Input-Output	EPA*	Ratio
Available final energy consumption	29782.7	29266.0	0.98
Energy & Industry	41268.0	42442.0	1.03
Net Transformation	13965.4	13176.0	0.94
Industry	3893.3	4472.9	1.15
Transport	13555.2	14137.9	1.04
Other	9854.1	10655.2	1.08
Total	42790.7	42442.0	0.99

Note: EPA totals adjusted for emissions not modelled in the Input-Output Table

In the latter a number of emission sources that are not modelled in BIO such as Waste and Land Use Change are ignored. An avenue for future work is the development of BIO to incorporate these emissions. In general however, the overall emissions are relatively similar, with EPA 1% lower than the IO and with relatively small variations by sector, except for the Industry sector at 15%.

5 Results

Structure of the Agri-Food Value Chain

Grouping the agri-food value chain into meat and dairy pathways, the structure of the agri-food value chain as described in the BIO Model is presented in Table 7. In order to summarise the 138 sectors in the BIO model, the value chains components are categorised as follows:

- Primary 1: The Primary Inputs from the same Value Chain (e.g. Milk for the Dairy Products Value Chain)
- Primary 2: Other Primary Inputs from the Value Chain (e.g. Milk for the Beef and Veal Meat Products Value Chain)
- Secondary 1: The Secondary Inputs from the same Value Chain (e.g. Dairy Processing for the Dairy Products Value Chain)

- Secondary 2: Other Primary Inputs from the Value Chain (e.g. Dairy Products for the Beef and Veal Meat Products Value Chain)
- Industry: All other Industrial Inputs into the Value Chain
- Services: All other Service Inputs into the Value Chain
- Energy: Energy Inputs into the Value Chain

Utilising the Leontief Inverse Matrix, direct and indirect inputs per unit of output are produced. Table 7 describes the share of the output multiplier from each of the meat and dairy value chains. The value chains can be grouped into three categories. The pastoral meat value chains (beef, sheep and other) have the highest share of primary inputs at about 25%, reflecting both the relatively extensive nature, combined with lower value added processing. The next group at about 18% contains the higher value added dairy, and the pig meat sectors, while the heavily industrialised poultry sector has the lowest share of value added in the Primary sector. Processing has the highest share of the multiplier with 40-65% for Secondary 1, highest for poultry and lowest for beef. Secondary 2, which is predominantly processed animal feed, is highest for the pig sector, reflecting its reliance on processed feed. Other services and industrial inputs (including fertilisers and pesticides) account for a similar proportion of the multiplier as the Primary sector. Overall energy inputs are relatively low at about 2-3%.

Table 7.
The Distribution of Value Across the Agri-Food Value Chain

Share of Multiplier	Primary1	Primary2	Secondary1	Secondary2	Industry	Services	Energy	Total
Beef and veal	18.9	8.4	43.6	6.8	6.6	12.6	3.1	100.0
Pig meat	13.7	3.9	49.0	12.4	6.2	11.6	3.2	100.0
Sheep meat	19.5	4.0	50.2	6.0	5.7	11.8	2.9	100.0
Poultry meat	6.1	1.1	64.8	4.9	6.6	13.2	3.4	100.0
Dairy Products	15.0	3.4	55.2	3.4	3.9	17.3	1.8	100.0

Emissions Associated with Final Demand

Table 8 describes the distribution of emissions across the agri-food value chain. The proportion of emissions from the Primary 1 sector is significantly higher in the large animal pastoral sectors (beef, sheep and dairy), where these emissions account for 81%-84% of total emissions. Over 80% of dairy emissions are at farm (primary) level which is consistent with the 80% finding of Finnegan et al. (2017). Poultry has relatively low primary emissions reflecting lower enteric fermentation in poultry versus ruminant animals. Seafood has negligible primary emissions.

Other farm level inputs are relatively small, with the next biggest share coming from Industry, which incorporates the contribution of fertiliser inputs and processed concentrate feed, the latter being particularly the case in aquaculture. The share of energy emissions varies from seven percent in the relatively low intensity, high enteric fermentation beef and sheep meat value chains to 46.5% for the fuel and energy intensive seafood processing sector and 25-38% in the industrialised pig and poultry sectors.

Table 8.
The Distribution of Life-Cycle Emissions across the Agri-Food Value Chain

Share of Multiplier	Primary1	Primary2	Secondary1	Secondary2	Industry	Services	Energy	Total
Beef and veal	81.7	1.3	0.3	0.0	10.2	0.0	6.4	100.0
Pig meat	46.4	0.9	1.4	0.0	25.8	0.0	25.4	100.0
Sheep meat	83.6	0.4	0.4	0.0	8.7	0.0	7.0	100.0
Poultry meat	23.2	0.9	2.9	0.0	35.0	0.0	38.0	100.0
Dairy Products	81.0	0.7	0.2	0.0	7.7	0.0	10.4	100.0

Table 9 reports the share of greenhouse gas emissions in terms of kT of CO_2 equivalent per €m of output. This represents the Carbon Footprints for the disaggregated meat, and dairy products. Carbon Footprints (CFs) represent the emissions intensity of production for the disaggregated Agriculture, Forestry and Fisheries (AFF) sectors. Emissions are expressed according to '$kTCO_2$ equiv per €m of Output' which relates emissions to the total value of output in terms of a standard monetary base. Results highlight beef and sheep meat as relatively emissions intense, demonstrating the highest emissions per unit output, followed by dairy, pigs, poultry and seafood. This indicates that the substitution from beef to dairy that has been visible since the elimination of milk quota in 2015 is expected to give rise to an overall reduction in emissions per euro of output from the agri-food sector. These results reflect the relative emissions intensity of livestock based products previously identified in LCA based studies (Wiltshire et al, 2009; Williams et al, 2006).

Table 9.
Greenhouse Gas Emissions (CO_2 equivalent) per €m of Output

	kTCO_2 Eq /€m of Output	Protein tonne/ €m output	Energy (M) kcal/ € m output
Beef and veal	3.59	54.9	932.6
Pig meat	0.90	73.7	1831.4
Sheep meat	2.53	37.1	630.8
Poultry meat	0.44	71.6	809.8
Dairy Products	1.02	36.5	854

6 Discussion

Increasing food production to meet rising global demand while reducing greenhouse gas (GHG) emissions is one of the greatest challenges facing the agri-food sector. There is a growing need to exploit international food market opportunities in a sustainable way that minimises the impact on land use and GHG emissions, as consumers across the globe demand enjoyable, safe, healthy, high quality, food products (Trienekens et al., 2012). Agri-food sustainability relates not only to primary production, but also has wider value chain implications. An IO model is a modelling framework which contains the flows across a value chain within a country. IO models have been disaggregated to have finer granular detail in relation to agricultural sub-sectoral value chains. National IO models with limited agricultural disaggregation have been developed to look at carbon footprints and also to look at the carbon footprint of specific agricultural value chains. In this paper we develop an agriculturally disaggregated input-output 'BIO' model to analyse the source of emissions in different parts of agri-food value chains.

The use of an IO model framework such as the BIO model offers a solution to the aggregate calculation of trade flows and emissions from both upstream and downstream processes, which are impractical to model at the individual product level. Moving towards an IO model framework also allows for investigation of the possibility of moving from an attributional supply chain approach (which measures the impacts of products strictly as a result of the material and energy flows throughout their supply chains) towards a consequential supply chain approach (which would include the potential impact of products on other production systems and supply chains).

Specifically, the approach presented in this paper facilitates new insights into the emissions related to the sub-sectoral elements of an agri-food value chain. Breaking up the value chain into components, the analysis shows that most value is generated at the processing stage of the value chain, with greater processing value in more sophisticated value chains such as dairy processing. On the other hand, emissions are in general highest in primary production, particularly for the ruminant meat sectors, albeit emissions from purchased animal feed are higher for poultry than for other value chains, given the lower animal based emissions from poultry than from cows or sheep. The analysis highlights these agri-food subsectors as distinctive supply chains where emissions per unit of output are much higher for beef and sheep meat value chains than for pig and poultry meat value chains.

The hybrid approach also allows us to not only breakdown the emissions profile of agri-food sectors in terms of the distribution of emissions along the value chain but also to delve into the emissions profile of primary production at farm level. The results demonstrate the minor contribution of energy emissions in contrast to those emanating from livestock and soils (fertiliser) at farm level. Accordingly primary production will not benefit from innovations associated with energy production but will continue to come under pressure to reduce emissions associated with primary production processes and to develop mitigation technologies at farm level. In particular, the rapid sectoral growth targets and recent expansion in the Irish dairy herd challenge the sustainable trajectory of the Irish agri-food sector.

However, the analysis described here has some limitations that need to be highlighted in relation to interpreting the results. Firstly, the linear nature of the IO model assumes that inputs are proportional to outputs, so potential future economies of scale are not taken into account. This limits the efficacy of this model in performing overly large-scale demand shocks or long-term analysis hypothesis testing. Secondly, the homogeneity assumption implies that each product and process is homogeneous within a sector, whereas in reality there is likely to be variation in performance and processes across the sector. Thirdly, the boundaries of the IO analysis are limited by the geographic region of a country. As such, important processes which may have large indirect impacts on global markets lie outside such boundaries (Duffy et al., 2017). The final caution is related to the assumption of 'Irish technology' associated with imports, which may distort emissions associated with imports (Lenzen, 2004; Wiedmann, 2007). Notwithstanding these limitations, this analysis also allows for the mapping of emissions (and associated 'hot-spots') along the agri-food value chain using an adapted EE IO approach. The modelling assumptions utilised are described in the BIO appendix.

7 Conclusions

In responding to growing global demands for food, Ireland has developed ambitious agri-food sector expansion targets (DAFM, 2015) which also highlight the importance of the measurement of the relative sustainability of agriculture and food exports, to provide the sustainability credentials for the 'Origin Green' export marketing campaign developed by Ireland's food marketing board (Bord Bia). This marketing campaign highlights the extensive, low-input, grass-based production systems employed in Irish food production, giving Irish food exports a competitive advantage in global markets. Ireland provides an interesting case study as while the sector has been successful in output expansion, there has been less success in terms of managing the trade off with emissions. Thus the maintenance of this competitive advantage in the face of rapid post quota dairy expansion in an agricultural sector which generates 30% of national emissions, poses challenges for data on emissions efficiencies along the wider agri-food value chains, in order to identify indirect suppliers and thus indirect emissions associated with final agri-food products.

Increasingly, LCA approaches are being adopted by researchers to address these issues. While there is a substantial literature employing process based LCA and IO-LCA research in an agricultural context, there are few studies that analyse sub-sectoral (ie, dairy beef, sheep etc.) emissions across the entire agri-food value chain. Authors such as Yan et al. (2013), West & Marland (2002) and Virtanen et al (2011) have used partial LCA methodologies in their IO approach, but have not incorporated emissions embedded in imported goods and services into the IO table, nor have they been disaggregated to include the wider agri-food sector. This is in part due to the complexity of the disaggregation involved in individually examining the allocation of inputs and outputs for agri-food sub-sectors such as dairy and beef production. However, this level of disaggregation is necessary to gain a greater understanding of the environmental sustainability of agricultural commodities across agri-food value chains.

This paper provides a detailed description of the development of a disaggregated agri-food bio-economy IO (BIO) model and makes a contribution to the literature as it extends the use of the hybrid IO-LCA to agri-food IO models, while also providing a new infrastructure that can be used for policy planning - combining both output impacts and ghg impacts across an agri-food value chain. One of the advantages of the approach in this paper is that modelling carbon at a sub-sectoral level allows to understand the trade-offs in land use in terms of different sectors, which is not possible in a single sector analysis. The differential ratios of beef and sheep to dairy for example, highlight the greater carbon efficiency of dairy production. In the post milk quota environment, there has ben an expansion of dairy relative to cattle in Ireland. However it is likely that if policy instruments were to be designed that built in greater carbon efficiency (emissions trading, carbon taxes or subsidies), such instruments could further exacerbate this trend, incentivising greater dairy specialisation in the sector in Ireland.

Addressing climate change challenges requires global solutions that will allow for the sustainable growth of agricultural output in the most efficient manner possible to meet the growing demand for food worldwide. While the overall conclusions in terms of the balance of value and emissions between primary and processing sectors have been previously reported in the literature, the application of this approach to a disaggregated agri-food IO is novel and is critical to assisting in the development and assessment of targeted policies and mitigation options across the different agri-food (meat) value chains. In particular one of the motivations for utilising a disaggregated agri-food IO or IO-LCA is to develop an analytic framework capable of highlighting emissions 'hot-spots' in different agri-food sub-sectors and across the value chain. This is turn facilitates the estimation of the relative impact of fiscal instruments such as carbon taxes or subsidies at the sub-sectoral level. As a result it widens the range of policy measures available for environmental impact reduction. In order to facilitate international cooperation in policy development in this area, it would be essential to have appropriate policy analytical tools and models. Extending this framework to other countries, for example by building on the European Commission's Agri-SAM models may be a potential avenue to facilitate such international developments.

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BIO Annex:

Appendix 1: Methodology and data requirements for calculation of emissions from livestock

Methane – CH_4

Ireland's emissions inventory applies a Tier 2[7] approach to calculating the main source of national CH_4 emissions, i.e., emissions associated with enteric fermentation and manure management from cattle production systems. For the other livestock sectors, a Tier 1 approach is utilised. From the NIR CRF tables, we derive simplified emissions factors per unit livestock or total CH_4 emissions by combining the implied emissions factors for enteric fermentation and manure management. Given sectoral output from the IO table and livestock population statistics from the CRF tables, we then convert livestock emissions factors to express the emissions in kilo tonnes per million euro of output (kt CH_4/ €m)

Nitrous oxide - N_2O

The other agriculture emissions which are a function of livestock numbers are Nitrous oxide (N_2O) emissions. This includes four categories: direct and indirect N_2O emissions from manure management, direct N_2O emissions from soils associated with manure application from housed animals, direct N_2O emissions from soils associated with urine and dung deposition by grazing animals. As with CH_4 emissions, simplified total N_2O emissions factors for each livestock (sector) are calculated by summing the four derived emissions factors categories. This calculation requires the following information and data sources:

- Direct N_2O emissions from manure management: These emissions factors are sourced directly from the CRF 'Table 3.B (b)'.
- Calculation of the indirect N_2O emissions from manure management by livestock category: This requires additional data on ammonia balances sourced from the EPA. Ammonia (NH_3) losses by livestock were converted to N_2O -N and subsequently N_2O to calculate the N_2O factor by livestock.
- Calculation of the direct N_2O emissions from manure applied to managed soils: This required supplementary data from the EPA in the form of representative N excretion rates and straw bedding factors per livestock type, as well as the N content of straw. The relevant N_2O soil emissions coefficients were taken from the NIR. Applying these data, the total kg of N excreted by livestock was adjusted to take account of direct and indirect ammonia losses from storage and housing (described above), as well as N additions from straw bedding.
- Calculation of the N_2O emissions from urine and dung deposited on soils by grazing animals: This required supplementary information from the EPA on the 'Allocation of Animal Wastes to Manure Management Systems' while the relevant N_2O soil emissions coefficients were taken from the NIR. Applying these data, N_2O emissions were calculated for the portion of manure deposited by grazing animals on pasture and expressed on a per unit livestock basis.

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[7] The 2006 IPCC Guidelines provide advice on estimation methods at three levels of detail, from Tier 1 (the default method) to Tier 3 (the most detailed method) (IPCC, 2006). Tier 1 employs IPCC Guidelines and default emission factors and other parameters whereas Tier 2 generally uses the same methodological approach as Tier 1 but applies emission factors and other parameters which are specific to the country. Tier 3 uses higher-order methods including emissions models tailored to address national circumstances.

Appendix 2: Methodology and data requirements for calculation of emissions from feed crops

The development of a crops sub-model enables the calculation of emissions from downstream input production (e.g. Carbon dioxide emissions from the production of diesel, fertiliser, pesticides, etc.) and the emissions associated with their subsequent transformation through on-farm processes (e.g. Nitrous oxide emissions from the interaction of fertiliser applications with the soils and Carbon dioxide emissions from on-farm combustion of fuel used for machinery operation). On-farm and off-farm input use emission factors and their sources are detailed in Tables 10 and 11 respectively.

Table 10.

Key on-farm emission and energy factors

		Emission or energy factor	Unit	Reference(s)
Nitrous oxide (N_2O-N)				
Synthetic N fertilizer application	On-farm	0.01 × N fertilizer applied (KG N)	kg N_2O-N/kg N	(IPCC, 2006; Carbon Trust, 2013; Vellinga et al., 2013)
Nitrogen leaching from synthetic N application	On-farm	0.0075 × fraction N applied (10% of N input to managed soils that is lost through leaching)	kg N_2O/kg N	
Atmospheric Deposition of nitrogen (N) volatilised from synthetic N	On-farm	0.01 × fraction N volatilised (3% of synthetic fertilizer N applied to soils volatilises as NH3 and NOX, 8% for livestock N))	kg N_2O/kg N	
Carbon Dioxide (CO_2)				
Diesel	On-farm	2.63 × diesel use (litres)	kg CO_2/l	IPCC (2006)
Gasoline	On-farm	2.30 × gasoline use (litres)	kg CO_2/l	IPCC (2006)
Kerosene	On-farm	2.52 × kerosene use (litres)	kg CO_2/l	IPCC (2006)
Urea application	On-farm	0.733× urea application (KG Urea)	kgCO_2/kg urea	IPCC (2006)
Lime application	On-farm	0.44 × lime application (Kg Lime)	kgCO_2/kg lime	IPCC (2006)

Table 11.

Key off-farm emission and energy factors

		Emission or energy factor	Unit	Reference(s)
Diesel	Off-farm	.38 × diesel use (litres)	kg CO_2/l	
Lime application	Off-farm	0.15 × lime application (Kg)	kgCO_2/kg lime	Carbon Trust (2013)
Urea	Off-farm	2.89 × urea application (KG N)	kg CO_2/kg N	Carbon Trust (2013)
P fertilizer	Off-farm	1.87 × P application (KG P)	kgCO_2/kg P	Carbon Trust (2013)
K fertilizer	Off-farm	1.80 × K application (KG K)	kg CO_2/kg K	Carbon Trust (2013)
Ammonium Nitrate	Off-farm	3.63× K application (KG N)	kg CO_2/kg N	Carbon Trust (2013)
Pesticides	Off-farm	8.40 × Active Ingredient (KG)	kgCO_2/kg active ingredient	Carbon Trust (2013)

While the NFS provides detailed farm level data on the quantity of inputs used in crop and pasture production as well as the quantities and cost of purchased feed, additional data were required to estimate inputs for which there was insufficient information. The NFS records information on the quantities of crops (home-grown and purchased) and fed to the different livestock enterprises. Inputs of seed, fertiliser, etc., and associated direct costs of crop production and pasture are broken down by crop type. IPCC (2006) emissions factors and NFS input use records were used to estimate on-farm emissions from lime and urea application, and diesel fuel use (Table 10). N_2O emissions resulting from the application of synthetic fertilisers were estimated by multiplying the direct and indirect N_2O emissions factors for synthetic fertilisers by the quantities applied as recorded in the NFS. Lime was treated as a capital land improvement expenditure item in the NFS and application rates are assumed on the basis of the total utilisable agricultural area (UAA) and assigned to crops accordingly.

NFS data on fuel and pesticide use is recorded at farm level in monetary terms and not allocated to individual crops. Fuel use by contract machine hire is also not recorded in the NFS (O'Brien et al., 2015). To calculate the emissions associated with these crop inputs a representative crops sub-model was developed. Field work processes were ascribed to each crop. Representative pesticide use factors (kg active ingredient/ha) were calculated for the main feed crops recorded in the NFS based on a national pesticide survey of arable crops (DAFF, 2004; DAFM, 2012) (Table 12). These fuel and pesticide use factors were applied to NFS records of the area of feed crops and pasture grown.

Table 12.
Pesticide application by Feed crop

	Economic Allocation Factor	kg Active Ingredient/ha	Average Number of pesticide applications
weighted barley total	0.92	2.318	8.585
weighted wheat total	0.95	4.823	13.471
weighted oats total	0.95	2.789	7.920
straw total (average of all cereal)	0.068	0.230	10.055
protein beans	1	3.25	5.48
triticale	1	2.8	8.1
potatoes	1	18.9	15.9
sugar beet	1	2.355	6.73
fodder beet	1	2.355	6.73
maize	1	2.295	3.05
arable silage	1	1.195	1.89
turnips	1	1.915	0.69
kale	1	0.9	1.96
rape	1	0.9	1.96
Grass (permanent pasture)	1	0.11	0.09
Silage	1	0.11	0.10
Hay	1	0.11	0.01

Source: (DAFM, 2012; DAFF, 2004)

Fuel use factors per litre/ha and per litre/hour (depending on the machine operation) were used to calculate representative fuel use data per unit area (Table 13). Fuel use factors for the range of field operations were adapted from Nemecek & Kägi, (2007). The creation of a representative set of field processes was informed by the national production research literature (DAFM, 2012; Phelan, 2017; Teagasc, 2011).

Table 13.

Fuel Use by machine operation per crop output (tonnes/ha)

	Wheat	Barley	Oats	Beans	Turnip	Fodder beet	Kale	Rape	Straw	Triticale	Arable Silage	Hay	Silage	Maize silage	Pasture	
Machine operation	Litres of Diesel Fuel by machine operation															Unit/output
Spray application	28.29	18.03	16.63	11.51	1.44		4.11	4.11	21.11	17.01	3.96	0.21	0.22	6.40	0.19	Litres /ha
Fertiliser spreading	18.90	18.90	18.90	6.30	6.30	12.60	6.30	6.30	18.90	6.30	6.30	6.30	6.30	6.30	6.30	Litres /ha
Topping (pasture)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.18	Litres /ha
Ploughing	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08	31.08	0.00	0.00	0.00	0.00	Litres /ha
Spring Tine harrow	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	0.00	0.00	0.00	0.00	Litres /ha
Rotary cultivator	16.80	16.80	16.80	16.80	16.80	16.80	16.80	16.80	16.80	16.80	16.80	0.00	0.00	0.00	0.00	Litres /ha
Chisel cultivator	0.00	0.00	0.00	18.48	18.48	18.48	18.48	18.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Litres /ha
Rolling	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	0.00	0.00	0.00	0.00	Litres /ha
Sowing	4.55	4.55	4.55	0.00	0.00	0.00	4.55	4.55	4.55	4.55	4.55	0.00	0.00	0.00	0.00	Litres /ha
Planting	0.00	0.00	0.00	0.00	20.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Litres /ha
Beet harvesting	0.00	0.00	0.00	0.00	0.00	123.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Litres /ha
Harvesting Maize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.31	44.31	0.00	0.00	44.31	0.00	Litres /ha
Combine harvesting	39.65	39.65	39.65	0.00	0.00	0.00	0.00	0.00	39.65	0.00	0.00	0.00	0.00	0.00	0.00	Litres /ha
Mowing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.13	5.13	0.00	0.00	Litres /ha
Tedding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	0.00	0.00	0.00	Litres /ha
Rowing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00	Litres /ha
Baling Hay/straw	1.36	1.36	1.36	0.00	0.00	0.00	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00	Litres /ha
Loading bales	0.64	0.64	0.64	0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop (straw)	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop(wheat)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop(barley)	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop(oats)	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop (Straw)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	L/tonne
Transport crop(Silage)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00	0.00	L/tonne
Transport crop(Other)	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.05	0.05	0.00	0.00	L/tonne
Fuel Use per unit output of feed crop																
	Wheat	Barley	Oats	Beans	Turnips	Fodder beet	Kale	Rape	Straw	Triticale	Arable Silage	Hay	Silage	Maize silage	Pasture	
Total Harvest operations	150.43	140.17	138.77	93.23	103.16	245.35	90.38	90.38	143.26	129.11	116.06	17.42	11.65	57.01	10.67	Litres /ha
Total Harvest operations	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.05	1.36	0.00	0.00	Litres /tonne

Source: Adapted from Nemecek & Kägi (2007)

* Average weighted cereal - straw

Appendix 3: Farm level data

Structure of NFS Data

The objective of the data structure in the NFS is to collect data so that a measure known as family farm income can be calculated. Family Farm Income is defined as Market Gross Output plus Farm Subsidies minus Direct Costs minus Overhead Costs. Market Gross Output, some Enterprise Specific Subsidies and Direct Costs can be allocated to the enterprise level.

Crop information in the NFS is stored at multiple levels

- Year
- Farm Code
- Crop Code

In other words, crop inputs are stored only for crops that exist on the farm. There are 66 different types of crop recorded in the NFS.

The collected information is stored in a number of different tables:

- Labour Input
- Crop Output, Uses (Feed x Animal Type, Sales, Seed, Waste, Closing Balance, Home Use)
- Fertilizer
- Expenses (Seed, Crop Protection, Transport Cost, Machinery Hire)
- Disposal of Feed stuff

In addition to the fertiliser table, there is another layer as different types of fertiliser are recorded. These files are combined together, so that direct costs and output can be identified in one file for one period for each crop type. Fertiliser usage is not identified separately in the direct costs, but combined together.

There is a time period issue with the data. Some crop volumes are utilised in the current year with the remainder used in the following year and so counts as a closing balance. Some of the crops used for the following year then come from the opening balance.

For cash crops, the value of output is the market price, while for non-cash fodder crops, the value of the output relates to the cost of production. Thus the price for opening balances and crops used in the current year may have different prices. As a result, an extension of earlier models is to separate crops into opening balance-based crop usage and current year harvested crops.

Crops are allocated by use, whether as feed, seed, sales, home use, waste or into the closing balance for the year. Crops that are fed to animals are further allocated to the animal enterprise (dairy, cattle, sheep, goats, deer, horses, poultry, pigs, etc.). We can thus identify the amount in terms of both volume and value (based upon calculated unit costs) of each crop type by animal enterprise. As we record the inputs of each crop that are used in the current year and because the dataset is a panel dataset, we record the inputs of crops that enter this year's account in the opening balance, we can track the input use such as fertiliser used in silage fed to sheep.

However this can cause time period problems as fertiliser can be bought in period one, stored as a closing balance and used in period two as an input into a crop that is harvested in period three, stored and part of an opening balance in year four and fed to an animal in that year. Thus in this case, a price change in fertiliser may have an impact on an animal based direct input three years later.[8]

Each animal system also contains other non-feed input costs which are allocated to each enterprise including:

- Veterinary and Medical
- Artificial Insemination
- Purchased Feed (Concentrate and Bulk)
- Miscellaneous Expenses
- Transportation

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[8] This animal may potentially be sold two years later, meaning that in a life-cycle situation the price change may affect a life-cycle margin for 6 years. However in the NFS, we incorporate direct costs in specific years, with change in value of the animals being incorporated in the gross output for a particular year.

- Labour

In the NFS, animal purchases are treated as a deduction from output rather than as an input cost. Changes in value as well as flows between cattle and dairy enterprises such as calves and heifers are also incorporated in the gross output. Farm direct costs are calculated as the sum of animal and crop direct costs less inter-enterprise transfers such as milk fed to calves.

Crop market gross output includes crops sold outside the farm, but excludes fodder crops used on farm as an input into the animal enterprises, which are treated as costs. Dairy market gross output includes milk sales plus the value of calves and the net transfer between the cattle system. Other animal systems include sales minus purchases, net transfers with dairy and value changes in stock. Land rented out, home-use, sales of other farm outputs like turf and contracting/rental of machinery are also included in market gross output at the farm level.

Market gross margin at either farm level or enterprise level can be defined as the market gross output minus direct costs, while gross margin (at both levels) is the market gross margin plus subsidies. Overhead costs (including depreciation) are calculated at the farm level and subtracted from farm level gross margin to get the family farm income, and when subtracted from market gross margin gives us a measure known as the net margin.

Preparation of Agricultural Inputs and Outputs

In our model, we take the CSO IO table as the primary source of our constraint data. While we take information from the national accounts and the NFS, we make any adjustments consistent with the macro totals in the CSO national accounts. In Table 14, we describe the allocation of output into domestic output and imports as well as exports. Due to balancing and definitional differences between the national accounts totals for these sectors and the IO totals, total output in the IO table is 1% lower than the national accounts, while imports are 6% higher and exports are 27% higher.

Table 14.
Output Adjustment to Ensure Consistency between National Acc. and Input-Output Table €m

	National Accounts				Adjusted			
€m	Output	Domestic Output	Exports	Imports	Output	Domestic Output	Exports	Imports
Cattle	1676	1502	339	173	1671	1488	247	183
Pigs	334	334			330	330		
Sheep	166	166			164	164		
Horses	151	151	73		149	149	54	
Poultry	112	112			111	111		
Milk	1542	1542			1527	1527		
Other	41	41			40	40		
Cereals	377	377			373	373		
Fruit & Veg	1257	346	227	912	1308	342	166	966
Forage	701	701			694	694		
Other Crops	102	102			101	101		
Seafood	504	337	370	167	511	334	270	177
Aquaculture								
Forestry	417	417	302		413	413	220	
HG Seed	19	19			19	19		
Contract Work	278	278			275	275		
Total	7676	6424	1312	1252	7688	6362	957	1326
IO	7688	6362	957	1326	7688	6362	957	1326
Ratio NACC:IO	1.00	1.01	1.37	0.94				

Source: CSO Agricultural, National Accounts (2010)

We use national accounts to source inputs by sector, therefore we scale all national accounts sectors on a pro rata basis. We disaggregate cereals in Table 15 using NFS data with aggregated cereals, fruit and vegetable, forage and other crops sectors.

Table 15.
Disaggregation of Feed into Sub-Components

Feed		
Cereals	Concentrate Own	0.93
	Concentrate Opening	0.07
Forage	Pasture	0.35
	Winter Forage Own	0.07
	Silage own	0.54
	Hay Own	0.04
	Winter Forage Opening balance	0.00
	Silage Op	0.00
	Hay Op	0.00
	Winter Forage Purchases	0.00

Source: Teagasc National Farm Survey (2010)

In Table 16 we describe the allocation of output by final use. We allocate a number of sectors as intra-agricultural flows including fodder and part of the cereals and the milk used as input into the cattle sector (taken from the NFS). Inputs into construction and the timber in the original CSO IO table are assigned to the forestry sector. Except for the food processing sector, there are relatively few inter-industry inputs into other sectors, which are allocated in proportion to the total share of inter-industry outputs from that sector. The rest of the outputs from primary agri-food are allocated to the secondary processing sector.

Table 16.
Allocation of Primary Output by Final Use (2010) €m

	Output (Agri-Food)	Output (Processing)	Output (Wood Processing)	Output (Construction)	Output Other	Total inter-industry	Final consumption	Gross fixed capital formation	Change in inventories	Exports f.o.b. (free on board)	Total Final uses €m
Cattle	0.0	1336.1	0.0	0.0	0.0	1336.1	0.0	-11.1	99.0	247.0	1671.0
Pigs	0.0	294.2	0.0	0.0	14.3	308.5	0.0	-2.8	25.0	0.0	330.0
Sheep	0.0	146.0	0.0	0.0	7.1	153.1	0.0	-1.4	12.0	0.0	164.0
Horses	0.0	0.0	0.0	0.0	0.0	0.0	92.0	-2.0	6.0	54.0	149.0
Poultry	0.0	73.9	0.0	0.0	3.6	77.5	26.2	-0.9	8.0	0.0	111.0
Milk	42.8	1294.5	0.0	0.0	65.1	1402.4	0.0	-12.7	137.0	0.0	1527.0
Other Products	0.0	36.0	0.0	0.0	1.8	37.7	0.0	-0.3	3.0	0.0	40.0
Cereals	25.7	306.2	0.0	0.0	16.2	348.1	0.0	-3.1	28.0	0.0	373.0
Fruit & Veg	0.0	274.1	0.0	0.0	13.3	287.4	786.7	-8.5	76.0	166.0	1308.0
Forage	674.8	0.0	0.0	0.0	0.0	674.8	0.0	-5.8	25.0	0.0	694.0
Other Crops	0.0	90.1	0.0	0.0	4.4	94.5	0.0	0.0	7.0	0.0	101.0
Seafood	11.1	172.9	0.0	0.0	9.0	192.9	38.7	-1.1	10.0	270.0	511.0
Aquaculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forestry	0.0	0.5	145.3	39.2	0.0	185.0	0.0	-1.0	9.0	220.0	413.0
Seed	19.2	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	0.0	19.0
Machinery Hire	254.4	0.0	0.0	0.0	0.0	254.4	0.0	0.0	21.0	0.0	275.0
Total	1028.0	4024.4	145.3	39.2	134.7	5371.5	943.6	-50.7	466.0	957.0	7688.0

Source: Teagasc National Farm Survey (2010)

The sources of inputs into the AFF Sector are presented in Table 17. Animal and crop inputs are presented in Tables 18 and 19.

Table 17.
ources of Input from the Primary Agriculture, Fisheries and Forestry Sector (2010) €m

	Total intermediate consumption	Product taxes less subsidies	Total consumption at purchasers' prices	Value added	Total inputs (=Total domestic supply row in Table 1)	Imports (=Imports in Table 1)	Total (=Total domestic supply + imports in Table 1)
Cattle	1027.0	10.1	1037.0	450.0	1487.0	183.0	1671.0
Pigs	228.0	2.2	230.0	100.0	330.0	0.0	330.0
Sheep	113.0	1.1	114.0	50.0	164.0	0.0	164.0
Horses	103.0	1.0	104.0	45.0	149.0	0.0	149.0
Poultry	77.0	0.8	77.0	34.0	111.0	0.0	111.0
Milk	1054.0	10.4	1065.0	462.0	1526.0	0.0	1526.0
Other Products	28.0	0.3	28.0	12.0	40.0	0.0	40.0
Cereals	257.0	2.5	260.0	113.0	373.0	0.0	373.0
Fruit & Veg	236.0	2.3	239.0	103.0	342.0	966.0	1308.0
Forage	479.0	4.7	484.0	210.0	694.0	0.0	694.0
Other Crops	70.0	0.7	71.0	31.0	101.0	0.0	101.0
Seafood	219.0	2.3	221.0	112.0	334.0	177.0	511.0
Aquaculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forestry	306.0	2.8	308.0	104.0	412.0	0.0	412.0
Seed	0.0	0.0	0.0	19.0	19.0	0.0	19.0
Machinery Hire	0.0	0.0	0.0	278.0	278.0	0.0	278.0
Total	4198.0	41.2	4240.0	2122.0	6362.0	1326.0	7688.0
IO	4198.0	41.2	4240.0	2122.0	6362.0	1326.0	7688.0

Source: Teagasc National Farm Survey (2010)

Table 18.
Animal Inputs (2010)

	Own Feed Current	Own Feed (OB)	Purchased Feed	Milk Substitution	Vet and Medical	AI	Transport	Misc	Labour	Other
Milk	0.10	0.11	0.31	0.13	0.12	0.11	0.05	0.03	0.05	0.00
Cattle	0.11	0.09	0.26	0.15	0.12	0.13	0.02	0.03	0.07	0.02
Sheep	0.14	0.13	0.32	0.16	0.11	0.07	0.03	0.02	0.03	0.01
Horses	0.10	0.14	0.16	0.14	0.23	0.08	0.06	0.03	0.01	0.03
Pigs	0.00	0.06	0.80	0.01	0.05	0.07	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deer and Goats	0.14	0.13	0.32	0.16	0.11	0.07	0.03	0.02	0.03	0.01

Source: Teagasc National Farm Survey (2010)

Table 19.

Crop Inputs (2010**)**

	Fertiliser	Labour	Seed (HG)	Crop Protection	Seed (Purchased)	Transport	Machinery Hire	Misc
Concentrate Own	0.34	0.00	0.00	0.30	0.13	0.00	0.21	0.01
Concentrate (OB)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Pasture	0.73	0.00	0.00	0.04	0.05	0.00	0.18	0.00
Winter Forage	0.25	0.00	0.00	0.11	0.15	0.00	0.41	0.07
Silage	0.32	0.00	0.00	0.00	0.00	0.00	0.60	0.08
Hay	0.50	0.00	0.00	0.01	0.00	0.00	0.47	0.03
Winter Forage (OB)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Hay (OB)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Forestry	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.59
Other Cash Crop	0.27	0.00	0.00	0.16	0.19	0.00	0.37	0.01
Potato, Fruit & Veg	0.20	0.06	0.16	0.19	0.15	0.00	0.13	0.12
Setaside	0.00	0.00	0.00	0.00	0.16	0.00	0.36	0.48
Sugar Beet	0.43	0.00	0.00	0.39	0.18	0.00	0.00	0.00
Total	0.41	0.01	0.02	0.09	0.06	0.00	0.36	0.05

Source: Teagasc National Farm Survey (2010)

Given that we use the Teagasc National Farm Survey to disaggregate the National Accounts inputs by enterprise, it is important to understand systematic differences between the two datasets. In Table 20, we compare the animal outputs for the NFS and CSO national accounts. Cattle and dairy totals are reasonably close, with a 5% higher CSO cattle total output figure than that derived from the NFS, reflecting the small farms that are not present in the NFS. The NFS dairy output is just 8% higher than the national accounts. There is however a large difference between the sheep output in the NFS and the CSO national accounts, reflecting the fact that the NFS sample does not cover the commercial pig and poultry farms (and horse producers that do not have other farm enterprises), output from these sectors are not comparable. On this basis, it may be worth engaging in a wider dialogue between CSO and the NFS in relation to differences between the different sources of data.

Table 20.

Teagasc National Farm Survey vs CSO National Accounts Animal Output comparison (2010) €m

	CSO	NFS	Ratio
Dairy	1541.9	1673.00	0.92
Cattle	1502.3	1437.00	1.05
Sheep	165.6	275.00	0.60
Horses	150.8	11.80	12.8
Pigs	333.7	24.60	13.6
Poultry	112.2	0.06	1898.3
Deer and Goats	40.8	0.00	n/a
Total (Dairy, Cattle, Sheep)	3209.8	3385.00	0.95

Source: Teagasc National Farm Survey (2010), CSO Agricultural, National Accounts (2010)

Note: Value of calf and animals moved from Dairy to Cattle in NFS

Appendix 4: Inputs

Table 21.
Structure of Inputs for Food and Beverages Sector (€m) (CIP 2010)

	Intermediate Consumption (Domestic)	Materials and fuels	Industrial Services	Non-industrial Services	Stock changes during year - Materials & fuels	Intermediate Consumption	Imports	Imports for IC	Goods for resale without further processing
Food	11410.0	8700.4	167.5	4597.6	33.1	13465.5	5077.7	2055.5	3022.2
Beverages	1206.3	882.2	32.8	586.6	56.6	0.0	547.3	295.3	252.0
Total	12616.2	9582.5	200.3	5184.1	89.7	13465.5	5624.9	2350.8	3274.1

Table 22.
Allocation of Inputs across Disaggregated Food Sectors (Domestic) (€m)(CIP 2010)

	Meat and meat products	Fish, crustaceans and molluscs	Fruit and vegetables	Vegetable, animal oils and fats	Dairy products	Grain mill products, starches/starch products	Bakery and farinaceous products	Other food products	Prepared animal feeds	Beverages	Total
Materials & fuels	3181	241	85	13	2889	28	245	1198	739	847	9465
Industrial Services	38	8	4	1	52	3	15	34	11	34	198
Non-industrial Services	108	14	34	4	32	0	91	4255	29	562	5129
Imports	644	63	20	4	518	21	82	530	212	316	2409
Domestic Intermediate Consumption	3326	263	123	17	2973	30	351	5488	779	1443	14793

Table 23.
Inputs from the Primary Agriculture and Fisheries sector (€m) (CIP 2010)

	Meat & meat products	Fish, crustaceans and molluscs	Fruit & vegetables	Vegetable, animal oils and fats	Dairy products	Grain mill products, starches and starch products	Bakery and farinaceous products	Other food products	Prepared animal feeds	Beverages	Total
Cattle	1336	0	0	0	0	0	0	0	0	0	1336
Pigs	294	0	0	0	0	0	0	0	0	0	294
Sheep	146	0	0	0	0	0	0	0	0	0	146
Horses	0	0	0	0	0	0	0	0	0	0	0
Poultry	74	0	0	0	0	0	0	0	0	0	74
Milk	0	0	0	0	1295	0	0	0	0	0	1295
Other	36	0	0	0	0	0	0	0	0	0	36
Cereals	0	0	0	0	0	12	0	0	280	14	306
Fruit & Veg	0	0	0	0	0	0	0	274	0	0	274
Forage	0	0	0	0	0	0	0	0	0	0	0
Other Crops	0	0	0	0	0	0	0	90	0	0	90
Seafood	0	90	0	0	0	0	0	83	0	0	173
Aquaculture	0	173	0	0	0	0	0	0	0	0	173
Forestry	0	0	0	0	0	0	0	0	0	0	0

Table 24.
Food to Food Flows (€m) (CIP 2010)

	Meat & meat products	Fish, crustaceans & molluscs	Fruit & vegetables	Vegetable, animal oils and fats	Dairy products	Grain mill products, tarches & starch products	Bakery & farinaceous products	Other food products	Prepared animal feeds	Beverages
Meat and meat products	676	0	0	0	0	0	0	0	0	0
Fish, crustaceans and molluscs	0	0	0	0	0	0	0	0	0	0
Fruit and vegetables	0	0	70	0	0	0	0	0	0	0
Vegetable, animal oils and fats	0	0	0	10	0	0	0	0	0	0
Dairy products	0	0	0	0	1042	0	0	0	0	0
Grain mill products, starches and starch products	0	0	0	0	0	11	0	0	0	0
Bakery & farinaceous products	0	0	0	0	0	0	201	0	0	0
Other food products	0	0	0	0	0	0	0	524	0	0
Prepared animal feeds	0	0	0	0	0	0	0	0	319	0
Beverages	0	0	0	0	0	0	0	0	0	679

Table 25.
Destinations of Food and Beverage Sectors (€m) (CIP 2010)

	Agriculture, forestry and fishing	Food & beverages and tobacco products	Non-Food Inter-Industry	Inter Industry	Final consumption of households, excl govt transfers	NPISH	Govt consumption plus transfers	Gross fixed capital formation	Exports	Output
Original IO	1154	3533	2130	6816	1724	-577	80	1	17680	25724
Meat and meat products	0	676	470	1146	361	98	17	0	2760	5379
Fish, crustaceans and molluscs	0	0	41	41	31	-11	1	0	286	466
Fruit and vegetables	0	70	19	89	15	-5	1	0	30	217
Vegetable, animal oils and fats	0	10	2	13	2	-1	0	0	8	28
Dairy products	23	1042	417	1482	319	67	15	0	1890	4765
Grain mill products, starches	0	11	6	17	5	-2	0	0	2	72
Bakery and farinaceous products	0	201	54	255	42	-15	2	0	192	621
Other food products	0	524	901	1426	691	-648	32	0	10478	10313
Prepared animal feeds	1131	319	0	1450	91	0	4	0	278	1358
Beverages	0	679	219	898	168	-61	8	0	1756	2505
Total	1154	3533	2130	6816	1724	-577	80	1	17680	25724