Extended Abstract
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Paper/Poster Title	**A nationally representative Bio-economic modelling of sheep production systems: Modelling the carbon footprint and economic performance of Irish sheep flocks**

Abstract prepared for presentation at the 98th Annual Conference of The Agricultural Economics Society will be held at The University of Edinburgh, UK, 18th - 20th March 2024.

Abstract	***200 words max***
This study details the development of bioeconomic model of sheep production systems. Drawing on nationally representative farm accountancy panel data and biological information linked to livestock activities the model is used to estimate the farm level economic and environmental performance of Irish sheep farms. Activity and production data when couple with biological parameters estimates enable the evaluation of the farm level Carbon Footprints (CF) and land occupation (Land Footprint) for the range of Irish sheep flocks. Along with the environmental footprint this framework enables the simultaneous estimation of the financial and technical performance of sheep farms operating at varying levels of production intensity and input use. Results highlight that while sheep farming in Ireland is largely pasture-based and extensive, significant differences in production intensity, land and input use exist across the distribution of farms. Results from this study show that the more profitable lowland sheep enterprises are characterised by higher technical performance, stocking and weaning rates, greater production intensity and greater emissions efficiency on a per unit basis.	

Keywords	Bioeconomic modelling, farm systems, LCA, GHG emissions
JEL Code	Environmental Economics see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	***100 – 250 words***
As EU agriculture policy enshrined in the CAP and underpinned by the Farm to Fork and Green Deal strategies evolves to focus on sustainability of farming systems in Europe (CAP,) there is an increasing demand for micro level analysis of the environmental, financial and social performance of agricultural systems. In response, a growing number of studies are based on whole farm systems models aimed at gaining a better understanding of the decision making process of farms across the distribution of farming systems, agronomic and environmental conditions (Louhichi et al., 2015). In the context of a growing population, emerging market trends for meat products and potentially conflicting sustainability and policy challenges more evidence on the sustainability of these ruminant meat production systems from both an environmental and economic perspective is required (Garnett et al., 2013). This study aims to explore these issues through the development of farm level	

bioeconomic modelling framework capable of analysing the economic and environmental performance of the national distribution of Irish sheep flocks.

Sheep production is 2nd most common enterprise on Irish farms and represent an important contributor to national agricultural production (CSO, 2020; 2023). Ireland is the fourth largest sheep meat exporter worldwide and the largest net exporter of sheep meat in the EU (Eurostat, 2022). While sheep production is generally considered to be pasture-based and extensive, large differences in production intensity, and land and input use exist. The application of the farm level modelling approach in this study using data from a nationally representative farm accountancy panel data (Hennessy et al., 2016) means that this variation in production practices across individual (real) farms can be captured along with the associated environmental outputs and financial performance (Louhichi et al., 2015).

Methodology	***100 – 250 words***

This study performs a Life Cycle Assessment (LCA) of the environment footprint of Irish sheep flocks. LCA provides an established and standardised method to evaluate environmental impacts across the life cycle of sheep production systems and has been widely applied to estimate the carbon foot printing of livestock production (Edwards et al., 2008; Yan et al., 2011). While the analysis presented in this study follows the ISO standard methodology, the Carbon Footprint calculations represent a partial LCA. This approach to calculating a carbon footprint of sheep farms has been applied in a number of previous related studies of UK sheep production, (Saunders et al., 2006; Williams et al., 2006; Jones et al., 2009). This study goes beyond a single-issue LCA, by also analysing the land use footprint and incorporating a detailed analysis of financial and technical performance (Murphy et al., 2017; Schmidinger et al., 2012; Thomassen et al., 2008). Unlike many representative farm models based on hypothetical and typical farm constructs this study estimates and compares the Carbon and Land Footprints for the full distribution of (real) Irish sheep farms as describe by the detailed Teagasc National Farm Survey (NFS). The CFs for sheep farms were calculated in this study according to a cradle to farm gate system boundary. This accounts for all GHG farm emissions up to the point of product sale from the farm (cradle to farm gate).

Results	***100 – 250 words***

Results highlight that lowland sheep farms exhibited higher gross margins driven by significantly higher gross output per unit hectare. Hill farms on the other hand were are much more dependent on direct income support: of the €206/ha gross margin earned on hill farms over the period €110/ha or 54% of this is attributable to subsidy payments, whilst on lowland farms almost 80% is earned from the market. Analysing the predominant midseason lowland production system highlights the best performing farms (ranked by gross margin/ha) are achieving significantly higher levels of output while simultaneously keeping a control over direct cost. Higher output levels are achieved through better technical performance reflected in higher stocking rates and weaning rates.

The average CF of lowland farms was estimated at 9.8kg of CO2-eq/kg LW, which was 13% lower than the average CF estimated for hill farms. The average CF of

lowland farms was within the range previously estimated by O'Brien et al. (2015) whilst the CF of hill farms diverged significantly.

Taking into account the carbon sequestration value of grassland reduces the carbon footprints on hill farms to 9.99kg of CO2-eq/kg LW (12% reduction) and lowland farms to 8.6kg of CO2-eq/kg LW (10% reduction). In line with O'Brien et al. (2015), the carbon sequestration rate had a relatively larger impact on reducing emissions for more extensive farms.

Looking at the breakdown of emissions across all sheep farms (Table 2), animal activities represent the largest source, with Tier I estimates of enteric fermentation and manure management comprising (64%) and (6%) of total emissions respectively. Other emissions include those emissions from soils (14%) and total emissions associated with feed production (16%).

Discussion and Conclusion	***100 – 250 words***

The farm level modelling framework developed in this study analysed GHG emissions from the range of sheep production systems consistent with IPCC reporting standards. Additionally, the emissions from upstream input production were estimated to provide a CF of sheep farms. In contrast to most other LCA studies this study enables the application of nationally representative panel data (Hennessy et al., 2016). This provides farm level estimation which is scalable and representative at a national level and thus more suitable for agronomic and policy recommendations across the range of farming practices. This framework can be readily extended to estimate CFs for cattle and dairy production systems as recorded in the NFS.

Results from this paper show that the more profitable lowland sheep enterprises are characterised by higher technical performance, stocking and weaning rates, greater production intensity and greater emissions efficiency on a per unit basis. This is in line with previous studies set in comparable production settings (Hyland, 2016; Jones et al., 2014a; O'Brien et al., 2016). Improved technical performance is reflected in the average carcass output per hectare of 332 kilos on the top third of lowland mid-season farms, versus 167 kilos on the bottom third of farms. This higher level of lamb output per hectare, combined with tighter control of direct costs is reflected in higher enterprise profitability. Extensive hill sheep entreprises on the other hand were less profitable and in line with previous studies (Jones et al., 2014b) demonstrated lower overall emissions but higher GHG emissions per unit output and lower production efficiency.

O'Brien et al. (2016) previously analysed nutrient surpluses, acidification and eutrophication as part of an LCA of sheep farms and found more intensive sheep systems had the greatest negative environmental impact for these factors. This highlights the potential conflict between carbon efficiencies and other environmental objectives not analysed here (Jones et al., 2009; Maier et al., 2001). New data within the NFS will enable future model development to capture some of these additional metrics to provide a more holistic sustainability assessment of sheep production systems.