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Counting Carbon; Does a Smaller Footprint Leave Less Impact? Defining Sustainability in the Dairy Sector.

Miles Middleton

December 2023

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Southill Farm, Staple Fitzpaine, Taunton, TA3 5SH
Tel: 01460 234012
Email: director@nuffieldscholar.org
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A
Nuffield (UK) Farming Scholarships Trust Report

Date of report: September 2022

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Counting carbon; Does a smaller footprint leave less impact? Defining sustainability in the Dairy Sector.
Scholar	Miles Middleton
Sponsor	Yorkshire Agricultural Society
Objectives of Study Tour	Reflect upon and interrogate the sustainability goals which define the contemporary discourse.
Countries Visited	USA, Republic of Ireland, The Netherlands, France.
Messages	1. A carbon footprint is as much subjective as it is objective. Methodological choices can allow results to be tailored by the author to support different opinions. 2. Carbon foot-printing is essentially a metric of efficiency, describing the carbon input required to produce a standardised unit of output. In relation to the Dairy sector, overall feed efficiency is the key driver of divergence between farms. 3. A drive for carbon efficiency is broadly, a drive for larger, more intensive, more technically efficient dairy farms. Usually with a greater dependency on arable products, purchased inputs and debt. 4. Consolidation and intensification present many challenges, both from the perspective of environmental protection, as well as wider fragilities of these systems in the face of future climatic, political and social challenges. 5. While efficiency and sustainability may not be concepts diametrically opposed, they should not be conflated. Sustainability is a far broader concept.

Executive Summary

Carbon footprints are presented within the contemporary media, commercial entities and frequently by government agencies as a proximate measure for sustainability.

Footprints are based on the science of Life Cycle Analysis (LCA), a footprint seeks to convey information about a specific environmental criteria, in a simple form, accessible to the public and non-technical stakeholders.

In the dairy sector, due to highly complex biological production systems, multiple outputs, use of co-products and relatively abstract components such as indirect land use change, there is significant opportunity for methodological divergence when calculating carbon footprints of milk.

Layered on top of this are debates around accounting for soil carbon sequestration, the application of carbon off-setting as well as the carbon equivalence of short-lived greenhouse gasses.

Fundamentally carbon footprints represent a metric of efficiency, describing the ‘carbon input’ required to produce a standardised unit of output.

Pertaining to the dairy sector, the key factor above all others that drives the carbon footprint of milk is feed efficiency. Given this, it is unsurprising that the correlation between the carbon footprint and profitability is strong.

High output, confinement dairy systems almost without exception feed higher levels of concentrate to cows making the ration more digestible and leading to higher milk output. In broad terms, this results in a lower carbon footprint per litre of milk when compared to more extensive grazing systems.

When asked to define sustainability within the dairy sector, expert stakeholders, largely converged of a set of overarching themes that should characterise a resilient and sustainable dairy sector.

These themes describe a self-perpetuating industry, that can continue in perpetuity, without eroding the natural or social capital upon which the industry, and wider communities, depend upon to function.

Natural capital has been described and defined as encompassing soil health, clean water and biodiversity.

Livestock systems can play an integral role in restoring and maintaining natural capital, but what is perceived as the highly intensive nature of dairy farming frequently presents barriers to this and presents risk of environmental damage.

Excessive nutrient surpluses generated by high intensity farming, present an elevated risk of eutrophication, water pollution and biodiversity loss.

Driven by the pursuit of efficiency, agriculture has seen a seismic and ever accelerating shift towards larger, higher yielding, more specialised farming systems with greater dependency on non-renewable resources, purchased inputs and capital assets.

Through capital interest, depreciation and asset costs these systems carry increasing levels of fixed costs, driving the necessity to maximise output even at very low marginal profitability and frequently at very low marginal efficiency.

In a world with growing demand for food, but with limited land and resources, it is imperative that the productivity of existing farmland is maximised. However, this must be done in a way that preserves the integrity of the land for future generations.

The use of metrics that incentivise the trading of nutrient efficiency for carbon efficiency while increasing the risk of environmental damage and drive dependency upon arable output, is of limited value.

Defining Sustainability is a question almost rhetorical in nature. It pertains to an almost spiritual relationship between people, animals and the land, unique to each locality, born of the climate, the geography and the culture. Where local tradition and religion once set the boundaries for these relationships, global institutions grapple with the granularity of these issues.

With respect to Agriculture, the use of carbon foot printing as a primary gauge of sustainability, has profound limitations.

While efficiency and sustainability may not be concepts diametrically opposed, the two should not be conflated.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, The Yorkshire Agricultural Society.

This report has been submitted to and accredited by Aberystwyth University.

1872 PRIFYSGOL ABERYSTWYTH UNIVERSITY

CONTACT DETAILS

Miles Middleton

miles.middleton@bishoptonvets.co.uk

07739997086

Nuffield Farming Scholars are available to speak to NFU Branches, Agricultural Discussion Groups and similar organisations

Published by The Nuffield Farming Scholarships Trust
Southill Farmhouse, Staple Fitzpaine, Taunton TA3 5SH
Tel : 01460 234012email : director@nuffieldscholar.org
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Introduction - What is a carbon footprint? What it tells us and what it doesn't' tell us about sustainability.

Over recent years increasing public awareness has been drawn to the threats of climate change and wider environmental sustainability concerns. Humans are consuming natural resources, transforming the landscape and generating waste at an entirely unsustainable rate (Hoekstra & Wiedmann, 2014). Emerging in the nineties as an indicator of environmental sustainability relating to different products and industries, the environmental footprint and following this, the carbon footprint have become widely recognised by the public (Monfreda et al., 2004).

Footprints seek to express environmental impact of products from a life cycle perspective, this encompasses the upstream impacts of all the components and resources used throughout the entire supply line (B. Ridoutt et al., 2015). The widespread recognition of carbon footprints as a stand-alone indicator of environmental impact, due to it's simplicity in communicating results, has allowed it to become the single focus of many contemporary debates around environmental sustainability. (Finkbeiner, 2009; Laurent et al., 2012; Laurent & Owsianiak, 2017).

Before discussing carbon foot-printing further, debating its merits and limitations, it is imperative that we better understand and define what a carbon footprint encapsulates, what it relates to and what it does not, what elements are included and what it tells us about the environmental impact and overall sustainability of agriculture.

Agricultural GHG National inventory and Global warming potential (GWP)

2006 saw the integration between agriculture and land use, land-use change and forestry by the Intergovernmental Panel on Climate Change (IPCC). "This integration removes the somewhat arbitrary distinction between these categories in the previous guidance,"(IPCC, 2006b). This development expanded the scope of national emissions inventories attributable to agriculture. This document sets out the principals of measuring and attributing GHG emissions.

Life Cycle Analysis (LCA)

Environmental footprints are based on LCA, a footprint seeks to convey information about a specific environmental criteria, in a simple form, accessible to the public and non-technical stakeholders (B. G. Ridoutt et al., 2016).

LCA is one of the most commonly used methods across all industries to allocate GHG emissions as well as other pollutants to any specific product seeking to encompassin the entire production cycle (Teixeira, 2015). LCA aims to standardise accounting in order to facilitate comparison both between different products and similar products produced within differing production systems, in contrast IPCC method quantifies GHG emissions using a national sector-based approach primarily for the purpose of producing national inventories (O'Brien et al., 2012; Schils et al., 2005). LCA was internationally standardized by the International Standardization Organisation, ISO 14040 and 14044 (ISO, 2006b, 2006a).

These ISO standards were used to develop sector specific guidelines for LCA analysis in the dairy sector by the International Dairy Federation (IDF) in 2010 and later amended within a revised document published in 2015 (IDF, 2015). This document was produced in collaboration with a series of international stakeholders including the ISO, The British Standards Institution, Food and Agriculture Organisation (FAO), IPCC, Carbon Trust, World Business Council for Sustainable development and The World Resource Institute.

However, despite efforts for standardization, LCA still lacks a fully harmonized approach, choices and hypothesises made by different authors as well at the data used can affect the results and comparability of different studies despite comparable subject matter (Pelletier et al., 2015; B. Ridoutt et al., 2015)

Systems boundaries

The FAO describes the sources of emissions which should be included are:	
(i) on-farm livestock emissions	including enteric fermentation, slurry storage and application and manure deposition on pasture by grazing animals
(ii)feed and forage production	including application of mineral fertilizer, soil cultivation, crop residue decomposition and related upstream manufacturing processes of inputs such as fertilizer
(iii) on-farm energy consumption	related to all elements of livestock production
(iv) Direct and indirect land use changes (LUC)	induced by the production of feed (excluding grassland and grazing)
(v) indirect energy	related to the construction and manufacture of buildings, plant and farm machinery.

(FAO & GDP, 2018).

Note that this source makes no reference to sequestration within grassland.

Functional Unit (FU)

According to ISO14044 only products with standardised FU can be compared using LCA (ISO, 2006b). FU should equilibrate the nutritional content of milk and allow comparison between milk of differing fat and protein content. However, standardization of this unit is not well established and two main correction formulae predominate within the literature (Baldini et al., 2017a).

FU	Formular	Source
Fat and Protein corrected milk (FPCM)	kg milk x [0.337+(0.116x fat%) + (0.06 x protein%)]	(FAO, 2010)
Energy corrected milk (ECM)	kg milk x [0.25 + (0.122x fat%) + (0.077x Protein%)]	(Sjaunja et al., 1990)

Both these equations give the same weighting to a standard litre of milk at 4% fat and 3.3% protein, but the different equations produce slightly different weightings as milk solids diverge from the standard. (Yan et al., 2013).

It is unfortunate that the IDF suggests FPCM but gives the equation relating to ECM potentially creating inconsistency within the literature (IDF, 2015).

LCA Modelling Principals

The LCA method (ISO, 2006b, 2006a) permits two different principals to be applied in life cycle inventory modelling, attributional modelling (ALCA) and consequential modelling (CLCA) (Baldini et al., 2017b; Pelletier et al., 2015).

CLCA seeks to establish a causal link between changes in demand generated by increased production and consequential increased supply of a given input. For example, increasing production of milk creates an increased demand for grain which creates additional demand for arable land etc. Inversely if milk production fell, demand for grain would also fall, the carbon footprint of the marginal supplier of said product is imputed into the cost of milk. (Dalgaard et al., 2014). So in this example it would be additional grain produced to meet the additional demand created by the expansion of the dairy sector, an author may deem that the marginal suppliers of grain exist at the agricultural frontiers and that new arable lands are created from previously unfarmed areas to meet the growing demand for additional grain.

ALCA allocates inputs and out puts based on a normative value, where possible the system should be divided into two or more sub-processes, or if this is not possible expand the system to include the additional functions related to the co-products. For example, in dairy this implies that beef produced by the dairy farm 'fulfils the same consumer need' and therefore substitutes beef produced within cow-calf suckler systems leading to an ‘avoided burden’ that forms a credit for the dairy system (Flysjö, et al., 2011a).

If allocation could not be avoided it should be based on a physical relationship between products. The IDF, (2015) suggested a method centred on feed energy requirements to produce a kg of beef or a kg of milk.

Finally, if any other relationship cannot be found the IDF (2015) suggest allocation of emissions based upon economic value of the output.

The IDF rules 2010 and 2015 represent a subset of ALCA with some specific rules. In the UK national guidelines called PAS2050 published in 2011 through collaboration between the British standards Institution, DEFRA and The Carbon Trust, (British Standards Institution., 2011) similarly represent a subset of ALCA, again with some specific rules (Dalgaard et al., 2014).

Application of LCA and factors leading to intrinsic inconsistency.

Dalgaard et al., (2014) compared the outcomes of four different LCA methods of calculating the carbon footprint of milk production, ALCA, CLCA, the IDF and PAS2050. These four methods were applied to Danish and Swedish milk production based on national life cycle inventory for each country obtained through data collected by ARLA and through national statistics and inventories.

Switching between different modelling systems resulted in significant differences in the carbon footprint attributed to milk production, increasing from 1.15 kg CO_2 e on Swedish dairy farms using CLCA to over 1.7 kg CO_2 e using the IDF model.

These differences where in large part due to the way that both direct Land Use Change (dLUC) and indirect land use change (iLUC) are calculated within the different models.

Land Use Change

There are two types of land use change that result in GHG emissions, direct land use change (dLUC), which occurs as a result of changing land management practice on a dairy farm, for example changing cultivation systems resulting in changes in soil carbon. While alternatively, indirect land use change (iLUC), occurs either through intensification of cropland or clearing forest to make way for cropland, at a remote location, in order to supply inputs for the dairy sector (Schmidt et al., 2015).

There are several different types of models for allocating iLUC with significant deviation in output between each method, this was demonstrated within the dairy sector by (Dalgaard et al., 2014) but similar discrepancies have also been described within the biofuels industry (Searchinger et al., 2008).

Schmidt et al., (2015) asserts that current land use reflects current land demand, consequently any increase in demand for land will ultimately increase land use. Any crop displaced by another crop will need to be produced elsewhere (Kløverpris et al., 2007; Schmidt, 2008).

While Audsley E et al., (2009) asserts that, given agriculture is a primary driver for deforestation, the LUC emissions for this deforestation should be distributed equally over all land occupied for commercial agriculture, resulting in a LUC factor of 1.4T CO_2e Ha^{-1} irrespective of land quality. Schmidt et al., (2015) refines the allocation of LUC emissions by differentiating differing land classifications based on land type, and potential. Land is classified into 'markets' such as arable land, grass land and range land. Global LUC emissions are calculated for each 'land market'. And these emissions for LUC are distributed within that land market. An interesting consequence of this method is that the underutilisation of highly productive land leading to low yields, will result to higher iLUC emissions per unit of output (Flysjö et al., 2012).

The PAS2050 method models iLUC by applying a 20 year amortisation period. (British Standards Institution., 2011). LUC emissions are applied directly to the products of deforested land and iLUC incurred through Brazilian soya bean meal equates to 740T CO_2 Ha^{-1} for conversion of rainforest to cropland, divided by 20 and attributed to the crop is 7.7kg CO_2e per kg of soya bean meal (FAO, 2010).

Flysjö, et al., (2011b) compared the implications of these differing methods for allocating iLUC upon confinement and organic dairy herds in Sweden. Organic herds invariably use more land per kg ECM but confinement herds use more soya bean meal. The choice of method used to calculate iLUC made significant differences to the relative emissions intensity of ECM.

Co-Product Allocation.

The handling of co-products is one of the most debated and unresolved issues surrounding LCA in the agri-food sector(Notarnicola et al., 2015). The IDF (2015) stated that allocation of emissions between feed co-products should be based upon economic value.

The allocation of GHG emissions to beef originating from the dairy sector causes significant variation within the reported emissions of milk. The effect of this variation is exaggerated in grass-based systems due to the lower milk yield per cow resulting in a higher ratio of beef production for each kg ECM (Flysjö, Cederberg, et al., 2011).

There is no convergence on 'the best method' of allocating emissions to co-products although economic allocation is the most commonly adopted, however this method is not compliant with the ranking criteria set out by the ISO (Baldini et al., 2017).

GHG Emissions From The Dairy Sector

Life cycle GHG emissions per kg of FPCM vary significantly across different dairy farms, (Henriksson et al., 2011; O'Brien et al., 2014a, 2014b) from as low as 0.6kgCO_2e/kg FPCM to as high as 2.13kgCO_2e/kg FPCM(O'Brien et al., 2014a, 2015).

Methane and Nitrous oxide emissions are by far the most significant GHG emitted from dairy farms (Rotz, 2018).

Anthropogenic CO_2 caused through use of fossil fuels and use of electric on farm composes only a small part of the overall carbon footprint of dairy (Mc Geough et al., 2012), however energy use incurred through the production of fertilizer dose make a more significant contribution on many farms (Casey & Holden, 2005).

Enteric Emissions

Invariably on almost any dairy farm, anywhere in the world, today as has historically been the case, on farm methane emissions form the largest part of any carbon footprint based on kg CO_2e/kg FU (Capper et al., 2009; Henriksson et al., 2011; Mc Geough et al., 2012; Morais et al., 2018; Rotz, 2018; Lorenz et al., 2019).

Typically, CH_4 exceeds half of all GHG emissions contained within LCA with the majority, over 80% of methane emissions resulting from enteric fermentation and the remainder the result of manure breakdown. (Aguirre-Villegas et al., 2022; Flysjö, Henriksson, et al., 2011; Mc Geough et al., 2012).

Enteric emissions per functional unit output are generally lower on high yielding confinement systems than on grazing and more extensive systems (Flysjö, Henriksson, et al., 2011; O'Brien et al., 2014b; Rotz et al., 2020).

The amount of methane produced in the rumen is broadly driven by the dry matter intake (DMI) of cattle but also heavily influenced by the makeup of the diet in terms of digestibility and fibre type (Sabia et al., 2020).There are differing methodologies that can be used for estimating enteric methane emissions, however, in the field of LCA, methane is usually estimated using IPCC guidelines,(Aguirre-Villegas et al., 2022) under this system, different tiers represent advancing levels of methodological refinement.

Methane enteric emission calculations. IPCC 2006	
Tier 1	Simply adopts a default emission factor, 121kg/ year CH_4 for North American Holstein cows which is reduced to 81kg/ year for smaller New Zealand type grazing animals.
Tier 2	Methane emissions are proportional to gross energy intake of feed and specific methane conversion factors. This method is adopted by many studies and is recommended by the IPCC.
Tier 3	These methods are based on more complex modelling systems and are country specific, they consider feed characteristics known to effect enteric fermentation

(Guzmán-Luna et al., 2021; IPCC, 2006a; Rotz, 2018)

Experimental evidence evaluating proxies for enteric methane emissions have shown DMI and digestible energy intake to be a “reasonably adequate” predictor of enteric emissions with an R^2 of 0.64 (Negussie et al., 2017).

Many models have used linear relationships to correlate between DMI, digestible energy and methane emissions, however enteric production does not follow a linear process, generally emissions rate gradually approaches an upper and lower limit. Non-linear models that predict methane production as a function of digestible energy intake and starch-fibre-ratio has proven reasonably effective in predicting methane production (Appuhamy et al., 2016; Stackhouse-Lawson et al., 2012).

Enteric fermentation is a complex process that cannot be easily represented by an equation (Rotz, 2018), given the high overall contribution of enteric methane to the carbon footprint of dairy relatively small inaccuracies in calculating enteric methane production can have a relatively large effect on the final carbon footprint of milk.

Modelling has demonstrated that short lived GHGs such as methane behave as ‘flow pollutants’ in contrast to ‘stock pollutants’ such as N_2O and CO_2. (Allen et al., 2018). The author proposes the GWP* method where, for flow pollutants, future climatic forcing effect of emissions depends upon the recent *change* in emissions.

However this implies the ‘grand-parenting’ of national methane ‘quotas’. The Paris agreement requires a 24-47% reduction in biogenic methane emissions by 2050 and how national budgets are allocated to different nation states is a matter of contention which may be challenged on the basis of ‘international fairness’ (Prudhomme et al., 2021).

Manure Handling and on Field Losses
On farm Nitrous oxide losses through manure storage, spreading and application of artificial fertilizer typically account for around 25-35% of total GHG emissions associated with dairy farming. (Mc Geough et al., 2012; O'Brien et al., 2014a)

Nitrous oxide has a very large CO_2 equivalence of 298kgCO_2e. This means that even relatively small quantities contribute significantly to the carbon footprint of dairy production (Rotz et al., 2010).

Ammonia (NH_3) losses from slurry while it is stored and spread are also a significant problem, up to 50% of nitrogen within slurry taking the form of urea which is broken down into NH_4 subsequently forming dynamic equilibrium between NH_4 and NH_3, if NH_3 is allowed to escape into the atmosphere as it volatilises the equilibrium will be pulled toward the creation of more NH_3.

Ammonia emissions are significant because they can be transformed in the environment into Nitrous oxide and other nitrogen compounds resulting in indirect GHG emissions. In addition to causing air pollution and eutrophication of natural ecosystems (Rotz et al., 2014).

Losses of both methane and nitrous oxide from manure have been shown to be significantly lower in grazing herds than in confinement systems (O'Brien et al., 2014b), this is because manure is applied directly to pasture without any storage or spreading process.

Soil Carbon Sequestration within LCA
Within the sphere of LCA, carbon sequestration by soils on dairy farms is applied inconsistently and is not included within the majority of LCA assessments (Knudsen et al., 2019). The amount of carbon held within soil always moves toward equilibrium, this equilibrium point is affected by management processes such as cultivation and application of manure. Conversion of land from cultivation to permanent pasture can result in significant increases in soil carbon over a 20-30 year time period, equating to around 0.46kgCO_2e/ kg ECM (Rotz, 2018). These gains are lost if the land reverts to cultivation.

It is recommended that soil carbon sequestration is excluded from LCA as guidelines from IPCC,(2006b) assume soil carbon reaches equilibrium after twenty years. According to (ISO, 2006a), sequestration should be calculated separately and applied as an offset.

However, it has been demonstrated that it is possible for managed grassland to continue to sequester carbon (Soussana et al., 2007, 2010)

Soil carbon sequestration was found to be capable of offsetting between 5%-18% GHG emissions from grassland dairy systems (Knudsen et al., 2019). Soil carbon sequestration has the potential to make a significant difference to conclusions around differences in GWP impact of different management systems (O'Brien et al., 2014b).

The issue of soil carbon sequestration and iLUC, represent another area of conflict and opportunity for divergence within LCA, while (Knudsen et al., 2019; Soussana et al., 2010) assert that conversion of cropland into grassland creates a carbon credit through sequestration, Audsley et al., (2009) would assert that the displacement of the arable crop results in indirect LUC emissions. The application of either of these positions will have a significant effect upon the final emissions calculation.

Relationship between CF and Farm Profitability

O'Brien et al., (2015) showed a correlation between carbon footprint and economic performance of dairy herds in Ireland. This was attributed to biological efficiencies in higher performing herds resulting in more efficient utilization of pasture, longer grazing periods, more milk per cow and lower use of concentrate per cow. Although not related to financial performance many of these variations were supported by Henriksson et al., (2011).

Summary

A consistent criticism of footprints has been the narrow focus, although strictly this is by design (B. G. Ridoutt et al., 2016). However, applying this lens to a complex and convoluted biological system with multiple outputs and that utilise a myriad of bye products from other industries, leads to a relatively abstract measure, that through methodological choices can be tailored to support the desired conclusions of the author.

"Net GHG emissions or CF has often been used to quantify the sustainability of a product. Sustainability is a much broader term though, including many other environmental impacts along with social and economic factors. – More needs to be done to integrate these other factors into a full life cycle assessment. Use of GHG emissions as a sole measure of sustainability is not appropriate." Alan Rotz, (Rotz, 2018)

"The risk is high that researchers and stakeholders misunderstand and/or inadvertently misuse foot printing results. An unfortunately large number of studies in the scientific literature and in popular media evidence occurrences of such situations, for example many studies using carbon footprint results to support claims about 'environmental sustainability', 'green products' or 'environmental friendliness.' – carbon footprint cannot act as acceptable proxies for systematically capturing the broad spectrum of environmental problems, thus making those claims inappropriate" (Laurent & Owsianiak, 2017).

To varying degrees, ruminant livestock systems can generate both positive and negative impacts upon local ecology and the wider environment. They can potentially form a key element of delivering ecosystem services but can also inflict significant damage, these outcomes are poorly captured by a carbon footprint (Von Greyerz et al., 2022).

There exists significant tension around the discourse of sustainability within agriculture and the vision of a sustainable future for food production(McNeill, 2019). Given the limitations of a carbon footprint at describing sustainability, this study will investigate the opinions of a broad range of stakeholders and seek to capture their views around how we should define, attempt to measure and address sustainability within the dairy sector.

Method

An online questionnaire exploring themes of sustainability with the dairy sector, agriculture and wider food production was created. Participants were selected based on specialism in the field and/or as a key stake holder within the industry. The survey aimed to encompass a broad range of stakeholders from across the breadth of dairy farming, food production, local government and other organisations with an environmental interest (figure 1). Participants were invited from different countries across the globe. Selection criteria also included accessibility and willingness/time to complete the anonymised survey. In many of the cases participation in the survey followed on or preceded a face-to-face meeting although this was not exclusively the case. Of the people selected only 21% submitted a completed questionnaire. The questionnaire was closed once thematic saturation had been reached.

Fig 1. Make up of respondents according to self-assigned category, pertaining to primary role, location, area of focus and highest academic obtainment.

Twenty-three participants responded, the responses were analysed using thematic analysis methods set out and guided by Braun & Clarke, (2006). Given the overlapping nature of the questions, responses were analysed as a whole, rather than on an individual question basis.

Primary themes are recorded in table 4. The total number of times each of them is mentioned or touched upon by participants is recorded in row A. In addition to this, respondents frequently focused on a particular theme, discussing this at length, a separate row B records the instances where this happened.

	Natural Capital and soil management	Protects Water	Biodiversity	Nitrogen efficency	Resilience (Environmental)	Resilience (cultural)	Rural Society	Financial	Geographically variable	Arable integration	Extensify/Reduce Input dependency	Social / Public acceptance	Animal Welfare	CF is simple/simplistic	CF is efficency	CF leads to intensification	CF methodology inconsistency	Technological advancement	Methane Reduction	Broad/ Holistic Term	
A) mention	18	13	16	6	7	5	6	12	2	4	12	2	6	10	5	4	4	6	2	8	
B) Focus	10	4	10	3		1	3	1		2	7	1						1			
Secondary Themes	**Natural Capital**					**Rural Society**				**Intensification challenges**				**Limitations of CF**							

Table 4 Primary and secondary themes discussed by survey respondents.

Responses where then organised into secondary themes clustered around preservation of natural capital, the importance of resilient social structures to support farming as well as themes around the often intensive nature of dairy farming resulting in a higher risk of environmental harm and lack of public acceptance.

Results and Discussion: Defining Sustainability in the Dairy Sector

When asked about the merits and challenges of carbon foot printing, eighteen of the respondents picked up one or more of the themes already discussed within this essay. Five respondents suggested that carbon foot printing was in many ways a better gauge of efficiency, than a measure of sustainability.

Given that enteric methane emissions represent more than half of GHG emissions on dairy farms and is directly related to the efficiency of feed conversion into milk (Aguirre-Villegas et al., 2022) this assertion is supported.

Moreover, Tier 2 methodology set out by the IPCC (2006) to calculate enteric methane emissions, bases this figure as a direct product of gross energy intake. Given firstly, that enteric emissions make up such a large proportion of overall emissions and that secondly, carbon footprints are reported on a per standard unit of output basis, simple logic informs us of a strong association between carbon footprint and feed conversion efficiency.

While it is misguided to state that efficiency and sustainability are unrelated, they should not be conflated.

Natural capital erosion

The most common theme that respondents picked up throughout the survey focused upon agricultural systems that are self-perpetuating and can last in perpetuity without eroding the natural capital upon which they, and wider society depend upon to function. This natural capital has been described and defined as encompassing soil, clean water and biodiversity (Goodland, 1997). Respondents inferred that systems that progressively deplete anyone of these resources are ultimately unsustainable.

Soil health is defined as the capacity of soil to function as a living system that sustains biological productivity, maintains environmental integrity and promotes plant, animal, and human health (Doran & Zeiss, 2000). "Soil health" cannot be directly measured thus quantifying the health of a soil is not straight forward (Karlen & Obrycki, 2019) different measures including soil organic carbon (SOC), water-stable aggregates (WSA), microbial biomass carbon (MBC),earthworm activity, water holding capacity, pH amongst others are all important to holistically assess the health of a soil, and while these factors are all linked, they do not necessarily neatly correlate (Karlen & Obrycki, 2019; Mcclellan Maaz et al., 2023)

Soil organic carbon is a measure of soil health frequently discussed within the scientific and grey literature, however there is currently no agreed standard approach to which methodology should be used to measure and compare soil organic carbon. Measurements vary significantly depending upon season, soil temperature and a multitude of other external factors.(Sabia et al., 2020). These uncertainties are cited as a reason that changes in soil organic carbon in managed soil is excluded when assessing GHG emissions (Knudsen et al., 2019). Despite difficulties in consistent assessment, soil organic carbon shows strong correlation with other soil health indicators (Mcclellan Maaz et al., 2023).

Using a multitude of soil health indicators, overall soil health was deemed to be better in pasture systems than arable land, unmanaged land and indeed comparable with soils surveyed in woodlands (see figure 2) (Mcclellan Maaz et al., 2023). The authors noted that samples were taken at a depth of 15cm and that this was not necessarily representative of soil health across a broader range of depths. Other studies have shown improved soil health indicators in pasture when compared to soils taken from forest (Saviozzi et al., 2001).

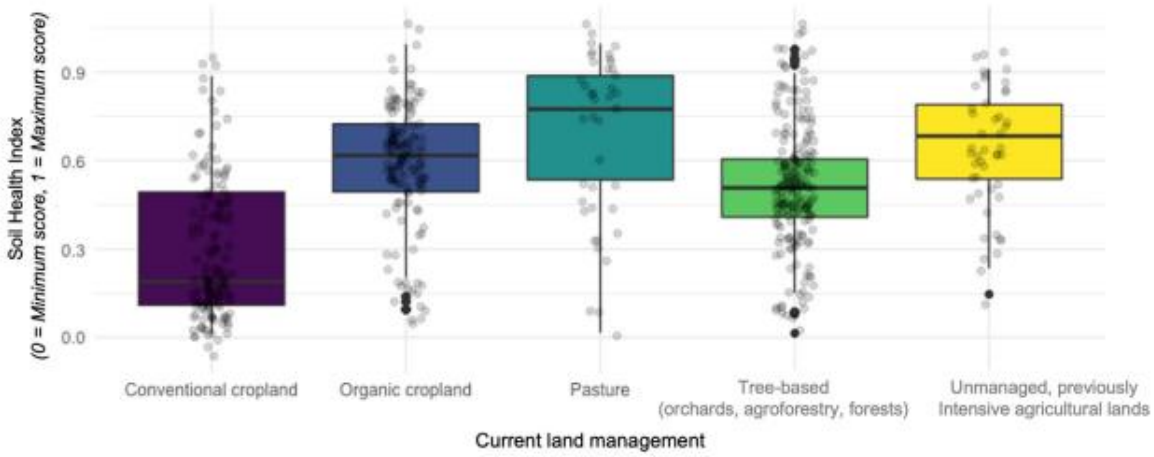
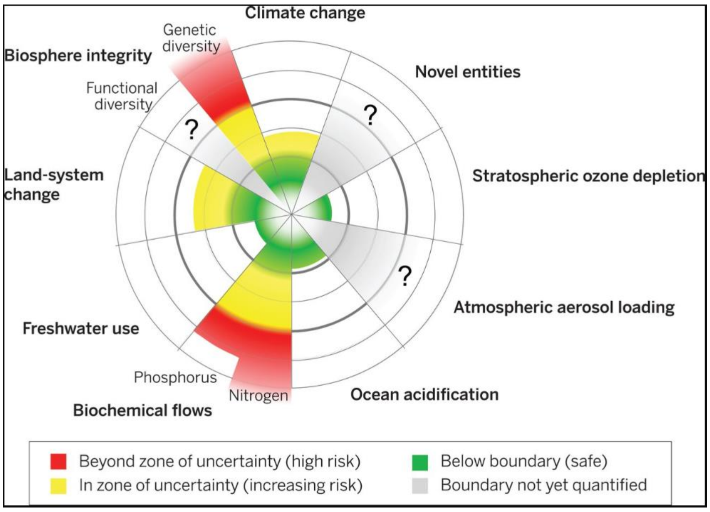


Fig. 2.Distribution of single level soil health indices, scored by the clustered single level model, across different current land uses and management categories. Conventional cropland had lower soil health indices than other land uses ($p < 0.05$) (Mcclellan Maaz et al., 2023)

The Theme described by survey respondents of a system that can self-perpetuate without eroding natural capital or exceeding its natural limits is an idea that broadly aligns with the concept of planetary boundaries. First described by Rockström et al., (2009) and further developed by Steffen et al., (2015) the concept sets out different dimensions or Earth system processes within which humanity must operate. These include climate change, biodiversity loss (Biosphere integrity), ozone depletion, freshwater use and biochemical flows of nitrogen and phosphorous amongst others. For each Earth system process, the authors seek to define a "safe operating space" within which humanity can continue to develop and thrive. Planetary boundaries define the limits of these safe operating spaces and transgressing any of these boundaries incrementally increases the risk of disrupting the capacity of the earth to exist within a Holocene-like state, moving from the zone of uncertainty through to a high risk of serious impacts.

According to Steffen et al., (2015) the Earth system processes where planetary boundaries are currently being exceeded to the greatest extent are those of biosphere integrity; loss of genetic diversity and biochemical flows of excessive nitrogen and phosphorous (see figure 3). These two key areas of sustainability mirror two of the remaining key areas focused upon by survey respondents.



Current status of the control variables for seven of the planetary boundaries.
The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone. The planetary boundary itself lies at the intersection of the green and yellow zones.(Steffen et al., 2015)

Fig 3. A graphical representation of planetary boundaries taken from (Steffen et al., 2015).

Nutrient use efficiency, and effect on water quality and natural biodiversity.

Nitrogen use and nutrient losses to the environment was one of the key focuses of seven of the twenty-three respondents, of the remaining respondents over half mentioned this as an area of consideration.

All livestock systems are limited to some degree in their ability to incorporate nutrients into products, due in large part to inherent inefficiencies of nutrient metabolism within both cattle as well as the plants they consume (Powell et al., 2010), leading unavoidably to losses into the environment which have the potential to cause negative impacts at both a local and global level. (Clark et al., 2007; Einarsson Christel Cederberg Jonatan Kallus, 2017) . While nitrogen losses can make a significant contribution to GHG emissions, the environmental impact of excess nutrients is far more wide ranging.

Nitrogen and Phosphate inputs in the dairy sector are dominated by inorganic fertilizer and purchased concentrates, the major outputs of these nutrients are embodied within milk and animal sales, (Flach et al., 2021; Löw et al., 2020; Mihailescu et al., 2014)

Nutrient utilisation is most commonly assessed using two indicators, Nutrient Balance (NB) and Nutrient use efficiency (NUE)(Dentler et al., 2020). Nutrient Balance is the difference between nutrient inputs and nutrient outputs, including P and N embodied in feed, fertilizer as well as those in bedding, livestock purchases, seed and exported manure along with atmospheric deposition and biological fixation. Results can be expressed either in terms of per unit of land (kg/ha) or in terms of unit output (kg/L) (Einarsson et al., 2017). Where the amount of input nutrient exceeds that of output nutrient it is often referred to as a 'Nutrient Surplus', where a surplus exists there is a risk of surplus nutrients being lost to the environment.

Nutrient Use Efficiency (NUE) is a dimensionless indicator of the ratio between the aggregated input nutrients and output nutrients. NUE dose not provide direct information on environmental impacts but informs on the efficiency with which nutrients are captured within the system (Gerber et al., 2014).

Of the respondents interviewed six identified either NUE or nitrogen surplus as important metrics of sustainability alluding to how excessive nutrient surpluses can adversely affect biodiversity. Only one respondent proposed that a maximum Nitrogen surplus per hectare should be considered as an indicator key metric of sustainability.

Flach et al., (2021) asserted that Nitrogen surplus of less than 50kg/ha are acceptable and can be incorporated into the soil as organic matter. EU guidance suggests the maximum desirable nitrogen surplus should not exceed 80kg/ha and exceeding this level presents an elevated risk of excessive losses to the environment. (EU Nitrogen Expert Panel, 2015) The guidance describes how at higher stocking rates and higher farming intensity NUE must be higher to avoid breaching this threshold. However Schulte et al., (2006) describes how these levels are not absolute and are affected by local climatic conditions such as rainfall and soil type. Excessive loss of nutrients into the environment is directly linked to biodiversity loss (EU Nitrogen Expert Panel, 2015). The same source also described how movement of nutrients from terrestrial ecosystems into water occurs within natural systems and within these systems a natural nutrient surplus is a requirement to sustain all ecosystems, it describes how agricultural systems with a NUE of greater than 90% are at risk of what it describes as 'nutrient mining' and depleting the soil of nutrients which are required for a functioning eco-system (See figure 4). There is an optimal level of nutrient surplus, however these levels are frequently exceeded within the dairy sector with studies showing surpluses of 255kg/ha(Cherry et al., 2012), 191kg/ha (Oenema et al., 2012) and 318kg/ha(Bassanino et al., 2007)

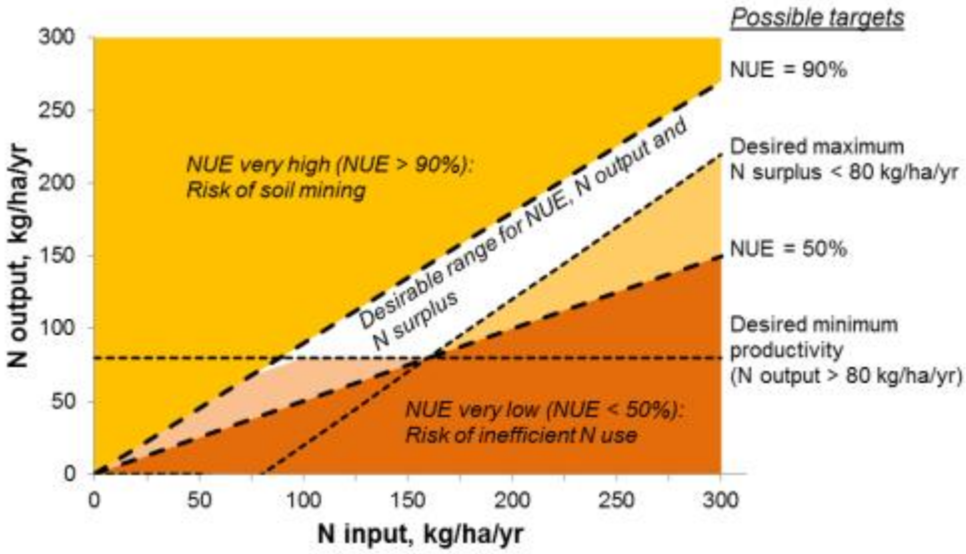


Fig 4. Conceptual framework of the Nitrogen Use Efficiency (NUE) indicator. The numbers shown are illustrative of an example system and will vary according to context (soil, climate, crop). The slope of the diagonal wedge represents a range of desired NUE between 50% and 90%: lower values exacerbate N pollution and higher values risk mining of soil N stocks. The horizontal line is a desired minimum level of productivity for the example cropping system. The additional diagonal represents a limit related to maximum N surplus to avoid substantial pollution losses. The combined criteria serve to identify the most desirable range of outcomes. (EU Nitrogen Expert Panel, 2015)

Agricultural intensification has been touted as one of the most promising ways to meet growing demand while minimising environmental impacts (Tilman et al., 2011), in the dairy sector this means increases in output both per acre and per cow, using predominantly confinement systems, invariably combined with increased use of concentrate feeding and typically inorganic fertilizer. Broadly, studies show that per unit of output, high out-put systems produce milk lower at emissions intensity than more extensive systems of dairy production, due in large part to the dilution effect of additional output on enteric methane emissions (Lorenz et al., 2019).

However multiple studies demonstrate that more intensive dairy systems, with higher levels of nutrient input reduce the overall efficiency with which nutrients are utilised. A law of diminishing returns resulting in a decline in NUE and an increasing nutrient surplus per ha (Dentler et al., 2020; Flach et al., 2021; Knudsen et al., 2019; Sabia et al., 2020). Nitrogen use efficiency and Nitrogen surplus for extensively managed dairy farms was 0.41 and 41.6kg/ha (Dentler et al., 2020) 0.44 and 37.9kg/ha (Flach et al., 2021)

A study of twenty one, intensively managed grazing systems in Southern Ireland found a mean nitrogen surplus of 175kg/ha and a mean NUE of 0.23, the study showed that higher nitrogen input per hectare in the form of inorganic fertilizer and concentrate feeding correlated with higher nitrogen surpluses(Mihailescu et al., 2014), based on other studies this trend extrapolated into confinement systems, where output per hectare is much higher leading to lower NUE and a higher nutrient surplus(Dentler et al., 2020; Knudsen et al., 2019). The authors concluded that low input, low output systems represented a more efficient use of external inputs, leading to lower nutrient losses into the environment and lower environmental pressure. Farm management and between farm variation in efficiency within the production system also had a significant effect on overall performance (Mihailescu et al., 2014). These conclusions are consistent with other studies(Chobtang et al., 2017; Einarsson et al., 2017; Flach et al., 2021; Knudsen et al., 2019).

A theoretical maximum utilisation of Nitrogen within ruminant production of between 0.45 and 0.5 (Dijkstra et al., 2013) demonstrates inherent and unavoidable nutrient inefficiencies of dairy farming. Dentler et al., (2020) demonstrated that in addition to declining utilisation efficiency of nutrients with increasing milk yield, high input systems relied much more heavily on feeding human edible feed stuffs, ten out of twelve high input dairy farms consumed more human consumable protein than they produced making them net consumers of human edible protein and energy, implying that these systems create additional demand for arable land. The study discussed how increased nutrient surpluses generated by high input systems generated an elevated risk of impacting marine, freshwater and terrestrial ecosystems leading to pollution and loss of biodiversity, these assertions where mirrored by the respondents of the questionnaire.

Biodiversity

Biodiversity loss was the mentioned more frequently than any other theme, with ten of the respondents choosing this as a major focus of discussions. In some instances biodiversity loss was directly linked to nutrient surpluses, while in others, the connection was made indirectly through discussion around the challenges of intensive land use and chemical inputs leading to biodiversity loss. Thirteen respondents advocated for more extensive systems which it was implied would improve biodiversity. All of these discussion points are supported by the literature and this link between high dependency on external inputs such as nitrogen fertilizer and purchased concentrates, leading to elevated nutrient surpluses and the subsequent risks of impacting water quality and biodiversity emerged as a key overarching theme of the study.

In terms of metrics of sustainability, biodiversity was the most popular response to this question with respondents indicating that this metric served as a sentinel indicator for broader environmental harm.

Biodiversity can be defined as the genetic variability among organisms, both within species and between species living within an environment. Agricultural practices may damage biodiversity (Sabia et al., 2020) and different methods exist to quantify this damage to biodiversity.

Biodiversity damage score measures the number of species detected within an occupied area and compares this to a baseline figure, the baseline figure is assumed to be natural forest because it is suggested that this is the land type that would arise without human distortion. (FAO, 2015; Tuomisto et al., 2012)

Several survey respondents asserted that appropriately managed grasslands can enhance biodiversity beyond that of unmanaged 'natural' ecosystems. This is supported by the FAO(2015) and by data gathered in the UK by Schryver et al., (2010). The study demonstrated organic fertile grassland to have a greater abundance of biodiversity than the baseline of 'natural woodland'. The study showed that as land use intensification increased, biodiversity declined. Also biodiversity was higher in organic systems vs non-organic. The study also suggested that where grassland borders arable land, biodiversity is enhanced, a position also articulated by survey respondents who advocated the incorporation of livestock systems into arable rotations.

A study by Sabia et al (2020) evaluating the effect of concentrate feeding on environmental impacts, high concentrate systems were again shown to deliver the greatest efficiency in terms of Carbon footprint per kg of FPCM, with biogenic methane contributing 75% of the carbon footprint in low concentrate systems compared to 57% for high input systems. However, the high concentrate systems resulted in far higher nutrient surpluses and demonstrated much a higher impact on biodiversity. (Sabia et al., 2020).

Delaby et al., (2020) discussed that although careful management of nutrient surpluses was essential to minimise wider environmental impacts, within dairy systems biodiversity can best be promoted by improving the quality and abundance of adjoining habitat, created strategically within the farm holding.

Extensification of dairy systems.

One third of respondents discussed in depth the challenges of intensive dairy systems or that a move towards more extensive dairy systems accompanied by a reduced dependence on the externalities of red diesel, compound fertiliser and imported feed, would both make dairy systems more environmentally sustainable and lead to a more resilient dairy sector, better able to meet the demands of a changing climate.

Kleijn et al., (2009) demonstrated that the relationship between nitrogen application and biodiversity is non-linear. In the broadest terms, only very small improvements in plant biodiversity were observed as nitrogen use fell from 250kg/ha to 75kg/ha, plant biodiversity increased more rapidly below this threshold, although the study also demonstrated significant complexity within this assertion. Moreover, this study only looked at the biodiversity effects within the farmed area and did not take account of the wider effects of terrestrial and freshwater eutrophication which can be associated with high nutrient surpluses.

Knudsen et al., (2019) compared differing production systems at varying levels of land use intensity. Organic farms showed lower levels of biodiversity damage as well as lower levels of ecotoxicity. UK, organic, grass-based systems, with an average stocking rate of 1.2ha/cow across the sampled farms showed an improvement in species biodiversity relative to the baseline of natural deciduous woodland, expressed as a negative biodiversity damage score of -0.28. The group of conventional, UK, grassland systems had an average stocking rate of 1.09ha/cow and were found to have a median biodiversity damage score of 0.37 although over two thirds of this damage was associated with the imputed damages of producing the imported feed. Output in FPCM kg/cow was 7411 and 6193 for UK, grass based conventional and organic systems respectively. Of the systems studied Danish, conventional, confinement systems producing average yields of 9599kg FPCM/cow/year with an average stocking rate of 0.88ha/cow were shown to present the highest risk of ecotoxicity and have the highest biodiversity damage score of 0.48. These farms also showed the highest levels of resource depletion in terms of fossil fuel use per kg FPCM, both directly and through costs associated with artificial fertilizer. In addition they where also found to be lower in terms of soil organic carbon which is positively correlated with the amount of grass fed since soil carbon sequestration is higher in grass land than in arable(Mogensen et al., 2014). The confinement system did however use less land per kg FPCM than any other system, although on examination it appears that the figures presented include only land used within the holding itself and do not include the land used to produce the arable crops needed to sustain the system.

While there is an emerging acceptance that protection of natural capital as a concept, is an integral element of sustainable agriculture, there is contested discourse as to how it can be measured, regulated and recognised at an industry level. Tension exists as to whether universal assessment criteria can be implemented at a national or international level or whether assessment must be tailored to meet local circumstances (Fleming et al., 2022).

Rural Society

Respondents discussed how systems need to be resilient in a multitude of different dimensions in order to overcome environmental, climatic and geopolitical shocks and stressors, this includes social dimensions. The ability of farming systems to thrive and adapt is dependent upon farms and farmers being embedded within thriving rural communities with broad societal investment within agriculture and diverse systems of farming bespoke to the local climatic, geographical and cultural context.

Healthy ecosystems, farm livelihoods and functioning rural communities are integral to food security (Chappell, 2019). While strategies around sustainable intensification seek to maximise productivity while manging narrowly defined environmental impacts, these endeavours frequently rely on capital intensive solutions that can exacerbate social and environmental vulnerabilities, consolidate production and lead to a concentration of power.(Gliessman et al., 2018)

Resilience can be viewed as the adaptive capacity of an agricultural systems to respond to climatic, environmental and economic challenges. Agricultural systems are complex social-ecological entities with reciprocal interactions between people, communities and the environment. These interactions operate at individual farm level, locally within communities and on a regional level (Petersen-Rockney et al., 2021).

Since the second world war, agriculture has seen a seismic and ever accelerating shift towards larger, higher yielding, more specialised farming systems with greater dependency on non-renewable resources, purchased inputs and capital assets (Capper et al., 2009). This has been accompanied by market consolidation, both up and down-stream of the farmer. This uniformity of markets, labour practices and advancement of technologies has allowed the expanding scale of modern farming (Busch, 2010). By many measures, including that of carbon footprint, these changes have driven improved efficiency (Capper et al., 2009).

These farming systems can offer financial rewards to farmers who can embrace new advancements first, typically larger farmers and others that can access capital-intensive technologies, inputs and resources first, giving them a temporary market advantage while the rest of the industry catches up or exits, before the next cycle (Busch, 2010). This process drives continual consolidation of farms and land ownership where farms take on increasing levels of debt to support increasingly capital-intense farming systems.(Petersen-Rockney et al., 2021). Through capital interest, depreciation and asset costs these systems carry increasing levels of fixed costs, this drives the necessity to pursue maximum output even at very low marginal profitability and frequently, in terms of nitrogen, at very low marginal efficiency, in order to cover these elevated fixed costs.

Conclusions

Carbon footprints are presented within the contemporary media, commercial entities and frequently by government agencies as a proximate measure for sustainability.

In the dairy sector, due to highly complex biological production systems, multiple outputs and use of co-products as primary inputs, there is significant opportunity for methodological divergence when calculating carbon footprints of milk.

Layered on top of this are debates around accounting for soil carbon sequestration, the application of carbon off-setting as well as the carbon equivalence of short lived GHGs.

Through its very nature the fact that a) enteric methane emissions account for over half of the carbon footprint, which in turn is calculated using gross energy of feed, and b) that carbon footprint is expressed per unit of production, implies that, pertaining to the dairy sector, carbon footprint is primarily a metric of efficiency.

Given this it is unsurprising that there is strong correlation between carbon footprint and profitability amongst dairy farms.

The drive for improved efficiency has had a profound effect on the nature of the dairy sector, leading to the consolidation and intensification of dairy farming creating challenges around the management of environmental impacts.

While grazing livestock can have a beneficial effect upon environmental outcomes, at high stocking rates supported by high levels of supplementary feeding these benefits can be very difficult to realise.

The quest for ever advancing levels of technical efficiency place a significant burden of investment upon dairy farmers. This frequently leads to heavily capitalised systems of production with high fixed costs.

These high fixed costs in turn promote the necessity for the pursuit of marginal production, while achieving this marginal production is facilitated by high levels of technical efficiency.

However, the pursuit of this marginal production generally leads to lower overall resource use efficiency in terms of nutrient use and purchased feeds.

High intensity systems exhibit a high stocking rate and frequently a high dependency on purchased fertilizer, concentrate feeds and red diesel.

In addition to the associated environmental risks, high levels of dependency on external inputs, as well as the inflexibility afforded by high fixed costs, may impair the resilience of intensive dairy systems in the face of a changing climate and accompanying political and social upheaval that may emerge as a result.

There exist examples of low input dairy systems, operating with minimal reliance on fossil fuels, chemical fertilizer and purchased feeds. These systems build natural capital and by many definitions of environmental sustainability, produce industry leading outcomes. They also offer an entry point for new entrant farmers. They also offer a means to harness the biological efficiency of dairy over beef systems, without building in the fixed costs that necessitate the pursuit of marginal production. Unfortunately, many of our current metrics, including carbon footprint penalise these systems.

In a world with growing demand for food, but with limited land and challenges to the availability of the resources required to produce food, it is imperative that the productivity of existing farmland is maximised. However, it is clear that this must be done in a way that preserves the integrity of the land for future generations.

The use of metrics that incentivise the trading of nutrient efficiency for carbon efficiency while increasing the risk of environmental damage and increasing dependency upon marginal arable output, is of limited value.

Defining Sustainability is a question almost rhetorical in nature. It pertains to an almost spiritual relationship between people, animals and the land, unique to each locality, born of the climate, the geography and the culture. Where local tradition and religion once set the boundaries for these relationships, global institutions grapple with the granularity of these issues.

With respect to Agriculture, the use of carbon foot printing as a primary gauge of sustainability, has profound limitations.

While efficiency and sustainability may not be concepts diametrically opposed, the two should not be conflated.

Recommendations

It is imperative that a more nuanced view is taken around the interpretation of carbon footprints with relation to food products.

Assessment of sustainability should strive to maximise land productivity while safeguarding natural capital as a primary goal.

System resilience is a key consideration in both environmental and social dimensions. How well can a system adapt to a changing climate and socio-political shocks.

Through recognising the protection of natural capital as a key sustainability goal, the industry can focus upon practices and systems that strive to meet this end.

Recognise small and medium scale dairy farming as a key element in the promotion of functioning rural societies.

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Annex 1 - Nitrogen Regulations in the Republic of Ireland

Nutrient surplus are commonly associated with high intensity farming and inefficient use of nutrients. While small nutrient surpluses can be incorporated into soil organic matter large surpluses are considered an indicator of environmental risk.

In 1991,The European Union Nitrates Directive (91/676/EEC) was introduced setting out guidelines to protect water quality in member states. These guidelines where implemented by each member state through a National Action Program. In the UK these led to the creation of Nitrate Vulnerable Zones (NVZs) and associated regulations. In Ireland these guidelines were legislated through the good agricultural practice (GAP) regulations first implemented in 2006, These regulations limit stocking rate to 170kg of organic nitrogen equivalent to 2.0 livestock units per ha.

The regulations also set out limits on application of slurry and inorganic nitrogen depending on factors such as crop type and vary dependant geographical location relating to local rainfall patterns.

The legislation sets out closed periods for spreading slurry during winter months when pasture demand and hence utilisation is at it's lowest.

Farmers can apply for a derogation which allows them to stock at up to 2.9 Livestock Units/ ha equating to 250kg organic N/ha. These farmers are subject to more stringent regulations and more frequent inspection regimes.

Stocking rates are monitored using the national cattle registration system and the land registration system also used to administer the basic payment scheme.

Derogations are principally taken out by the majority of dairy farmers and other high intensity livestock operations.

Annex 2 - Nutrient Regulations in the Netherlands.

There are around 1.6 million dairy cows in the Netherlands on around 15 thousand farms with an average herd size of just over 100 cows, in 2020 the average milk yield across the Netherlands stood at 9255kg/cow/year, the highest in the EU. Along with the pig and poultry sectors, the dairy sector is heavily reliant upon imported feed concentrate, this results in very high nutrient surpluses across the Netherlands. (Hoes & Aramyan, 2022)

Over the last four decades, Dutch farmers have faced increasing restrictions directed at improving environmental outcomes. Dutch farmers are subject to the same EU regulations introduced in 1992 that apply in Ireland. Like in Ireland Dutch farmers are currently able to apply for a nitrogen derogation allowing them to apply up to 250kg/ha of organic nitrogen providing that at least 80% of their farm land is under grass. There are however concerns that this derogation will be taken away from the Netherlands by the EU due to failure to reduce environmental nitrogen levels at a fast enough rate, meaning that the maximum rate of organic nitrogen that can be applied will be reduced to 170kg/ha.

The heavily capitalised and intensive nature of the Dutch dairy sector means that the majority of dairy farmers already produce more manure than they are able to apply under the derogation, as a consequence of this farmers export manure to other farmers with some being transported considerable distances, sometimes into Germany to be applied. Dairy farmers pay the recipients of manure to receive these nutrients. The export of nutrients represents a significant cost to Dairy farmers in the Netherlands and if the EU derogation is taken away, it will inevitably necessitate that more manure is exported creating upward pressure on the market for accepting nutrients.

In 2016 Phosphate quotas where introduced effectively capping the number of cattle within the Netherlands. Phosphate quotas where allocated to individual farmers based on 2016 livestock numbers, these quotas can be traded but these trades must be sanctioned by the Dutch government who make reductions to the traded quota. These reductions to the total amount of quota each time quota is traded means that overall the number of cattle in the Netherlands will fall over time.

Dutch farmers are obligated to fill in and annual assessment called 'KringloopWijzer' (nutrient cycle assessment). This estimates nitrogen and phosphate flows and use efficiencies.

Annex3 - Questions offered through online questionnaire.

"Defining sustainability in the dairy sector."

1. I hereby give my informed consent to take part in this research project. I know that I am free to withdraw at any time without giving a reason.

2. Where are you currently resident?

Great Britian
Ireland
Continental Europe
North America
Oceana
Other

3. Which of these options best describes your principal role within agriculture and food production?

Farmer/ Primary producer
Consultant/Technical Advisor to farmers
Agricultural Supplier
Local or National government
Academia
Food processing and retail
Journalist/ Public communications
Other

4. In which area do you predominantly focus your work?

Dairy
Non-dairy ruminant
Non- ruminant livestock
Arable/ Horticulture
Non- land based food production
No specific area

5. Have you completed any of the following academic qualifications? (tick the highest that applies).

High School (GCSE/ O-Level)
College (A-Level/ NVQ etc.)
Bachelor Degree
Postgraduate Qualification

6. In your own words, give your interpretation of sustainability as it relates to agriculture and food production?

7. To what extent do you feel it is possible to measure/quantify sustainability?

7.a. A carbon-footprint is often used as a metric that purports to represent sustainability. What do you feel are the benefits, limitations and potential dangers of this?

7.b. Are there any other metrics that you feel are important?

8. In your opinion, what are the most important environmental challenges facing dairy farming?

8.a. To what extent can these challenges be mitigated?

9. In your opinion, how might dairy farming and wider ruminant livestock farming change by the year 2050 to meet environmental and sustainability challenges?

10. What if any, is the role of grassland within future food production systems?

10.a. How might future grasslands / grassland farming systems, differ from what we see today?

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