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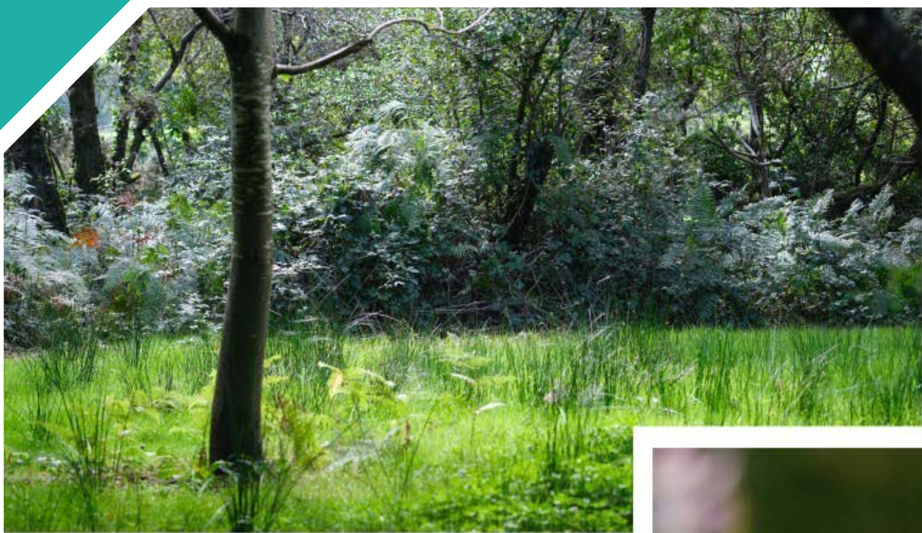
epa Research

# Diversification of Dairy and Beef Production for Climate-smart Agriculture

Authors: Maria Markiewicz-Keszycka, Paul Hynds, Donal O'Brien, Maeve Henchion and Áine Macken-Walsh

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Rialtas na hÉireann
Government of Ireland

# Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

## The work of the EPA can be divided into three main areas:

**Regulation:** Implementing regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

**Knowledge:** Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

**Advocacy:** Working with others to advocate for a clean, productive and well protected environment and for sustainable environmental practices.

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> Urban waste water discharges;
> The contained use and controlled release of Genetically Modified Organisms;
> Sources of ionising radiation;
> Greenhouse gas emissions from industry and aviation through the EU Emissions Trading Scheme.

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> Design and implement national environmental monitoring systems: technology, data management, analysis and forecasting;
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> Oversee the implementation of the Environmental Noise Directive;
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> Coordinate and fund national environmental research activity to identify pressures, inform policy and provide solutions;
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> Work with international and national agencies, regional and local authorities, non-governmental organisations, representative bodies and government departments to deliver environmental and radiological protection, research coordination and science-based decision making.

## Management and Structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Lead organisation: University College Dublin

## Identifying pressures

Data reported under the Habitats Directive suggest that, overall, farming has a negative impact on nature and biodiversity, particularly on intensive farms. Climate change and biodiversity loss are expected to have far-reaching market, economic, business and policy impacts on the agricultural sector. If new practices are not implemented, penalties for missing EU carbon reduction targets and lack of sustainability in the agri-food sector could significantly affect farmers' incomes. This desk study sought to develop recommendations for the pro-environmental diversification of dairy and beef farms. The study design encompassed (1) a literature review presenting research on pro-environmental diversification in Ireland, the UK and New Zealand; (2) interviews with innovative farmers from Ireland, the UK and France, which helped to establish their profiles, their motivations and the challenges they encountered; (3) a national online survey of beef and dairy farmers' attitudes towards diversification opportunities; and (4) modelling the environmental impact of diversification scenarios.

## Informing policy

The results of this research indicate the following:

- Holistic studies are urgently needed to investigate agroecological farming practices that can decrease greenhouse gas emissions and strengthen biodiversity and ecosystem services on Irish dairy and beef farms.
- Irish, UK and French farmers who have already implemented pro-environmental diversification on their farms follow a new peasant farming model, as opposed to the entrepreneurial model that has been promoted by the Common Agricultural Policy. It is important to promote peasant farming through policies, as this will lead to the creation of a resilient agricultural sector and contribute to achieving EU environmental and climate objectives.
- The national survey results indicate that lack of know-how and lower profits were principal barriers to adopting pro-environmental agriculture among conventional dairy and beef farmers.
- Currently, non-governmental organisations, pro-environmental farmers' associations and organic farming associations are the main contributors to promoting knowledge on agroecology and nature-inclusive farming. The increased availability of pro-environmental agricultural courses through farming advisory boards, non-profit organisations and agricultural colleges will most likely prove essential for future uptake of pro-environmental agricultural diversification activities.

## Developing solutions

Promoting diversification of land use is proposed to be one of the measures needed to fulfil the Climate Action Plan 2019 targets. Ireland is committed to promoting the diversification of activities and low-carbon practices at farm level and in the wider rural economy.

CattleDiVersa provides suggestions and solutions that address the challenge of designing environmental schemes that are efficient for nature and attractive for farmers. The results of this project will help policymakers design win–win solutions that make economic sense to farmers by ensuring that their future actions will fully comply with Ireland's duties and commitments concerning environmental legislation and climate policy. All resulting knowledge transfer media are designed to deliver two-way exchanges, allowing both top-down and bottom-up discussions that enhance all stakeholders' understanding of the alternative activities and income streams, and to address limiting factors and issues. Such an approach reduces barriers to uptake at the social, economic and cultural levels.

**EPA RESEARCH PROGRAMME 2014–2020**

# Diversification of Dairy and Beef Production for Climate-smart Agriculture

## (2019-CCRP-DS.20)

## EPA Research Report

Prepared for the Environmental Protection Agency

by

School of Agriculture and Food Science, University College Dublin; Environmental Sustainability and Health Institute, Technological University Dublin; and Teagasc

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# Executive Summary

Farm diversification incorporates various elements, such as diversification of income streams and land utilisation and the inclusion of non-farm enterprises. For the purposes of the CattleDiVersa project, we focused on the pro-environmental diversification of farms, defined as "on-farm change or changes in agricultural practices that benefit the natural environment, promote agrobiodiversity, potentially leading to lowering of GHG [greenhouse gas] emissions".

The main objectives of the CattleDiVersa project were:

- to provide a detailed analysis of pro-environmental solutions proposed in the scientific literature;
- to provide a detailed analysis of interviews with Irish ($n = 15$), UK ($n = 7$) and French ($n = 7$) farmers who have already implemented diversification practices on their farms;
- to provide analysis of a national survey to understand attitudes among Irish beef and dairy farmers and behavioural barriers to implementing diversification activities;
- to undertake a life cycle assessment of three diversification options recommended by the national advisory body, Teagasc, to dairy and beef farms: mixed grass–white clover (GWC) swards, organic farming and agroforestry;
- to provide recommendations for governmental support and improved legislation to encourage systemic change in this area.

The literature review results reveal that studies examining the impact of pro-environmental practices encompass a broad spectrum of methods and approaches, including hedgerow and field margin management, mixed grazing, rare livestock breeds, multispecies swards, organic farming and agroforestry. In contrast, attitudinal research studies predominantly concentrate on a more limited set of practices, primarily related to forestry, bioenergy crops and organic farming, with minimal overlap between the two.

The results of the interviews with farmers reveal that, in most cases, implementation of pro-environmental diversification was linked to alternative farming systems such as organic agriculture, regenerative agriculture, agroforestry and permaculture. The main challenges associated with implementing pro-environmental diversification were unclear regulations, lack of information and labour intensiveness. Farmers who embraced pro-environmental diversification placed greater emphasis on values associated with the environment, economy, autonomy and society, with less priority placed on maximising profit, especially when it was tied to potential environmental harm. Farmers' decisions to pursue pro-environmental diversification were primarily motivated by ecological principles and a sense of responsibility towards environmental protection.

The results of the nationwide survey conducted as part of this project indicate that the most common barrier to pro-environmental behaviours is a lack of "know-how" (reported by 37.9% of respondents), followed closely by concerns about lower profit margins (reported by 36.1% of respondents), with pro-environmental farmers overwhelmingly citing the former and conventional farmers citing the latter. Overall, pro-environmental belief scores were significantly associated with adoption of organic farming and employment of pro-environmental land management measures, signifying that positive attitudes towards pro-environmental agriculture are conducive to pro-environmental behaviours.

The results of the life cycle assessment illustrate that GWC swards reduced global warming potential (GWP) on a product basis by 9% for dairy and 3% for suckler beef. Incorporating white clover into ryegrass swards improved productivity and resource efficiency in conventional cattle farming. This was accompanied by a reduction in methane and nitrous oxide emissions, primarily due to decreased synthetic fertiliser usage. Higher stocking rates led to increased beef output.

Carbon sequestration in clover had a more substantial mitigating impact on greenhouse gas emissions for dairy production than for beef production. However, the impact on freshwater eutrophication potential and marine eutrophication potential (MEP) was limited, with an increase in MEP attributed to the higher nitrogen content in GWC systems. Organic farming had the lowest environmental impact per unit of land, and

reduced GWP and non-renewable energy depletion. However, without carbon sequestration, organic farming had the opposite effect on the GWP of milk production and increased acidification potential and MEP per product unit. Declines in productivity partly explained increases in impact per unit of product and increases in land occupation. Partial conversion (10–20%) of grassland to silvopasture decreased milk and beef output and generally positively influenced GWP and MEP per hectare. Carbon sequestration tended to be greater in agroforestry than grassland, but life cycle assessment models struggle to accurately quantify the influence of management change on this process.

# 1 Introduction

Many definitions are used to characterise pro-environmental farm diversification, drawing on perspectives provided by Sutherland *et al.* (2016), Morris *et al*. (2017) and Ridier and Labaethe (2019). For the purposes of this study, pro-environmental diversification has been defined as “on-farm change or changes in agricultural practices that benefit the natural environment, promote agrobiodiversity, potentially leading to lowering of GHG [greenhouse gas] emissions” (Markiewicz-Keszycka *et al.*, 2023). Diversification is an agricultural strategy regularly reported to have a positive influence on environmental sustainability and food security. This strategy was common on European farms before the green revolution in the 1960s (Clark and Tilman, 2017). Many different options exist for diversifying agricultural systems. Several of these options have multiple benefits. For example, Lee *et al.* (2003) reported that planting 16-m-wide woody riparian margins, in the correct place, around maize and soybean field plots in the USA reduced surface run-off and trapped over half of the incoming sediments and nutrients from cropland. Jahangir *et al.* (2014) found that a mustard catch crop reduced groundwater nitrate ($NO_3^-$) levels underneath an Irish field of spring barley and mitigated an indirect source of greenhouse gas (GHG) emissions relative to a conventional barley field with no vegetative cover. Finn *et al.* (2013) showed in a continental-scale field experiment that grass–legume mixtures combining four species outperformed the best monocultures in terms of total yield in about 60% of sites, reduced weed invasion and improved resource complementarity. Implementing diversification practices on livestock farms is therefore likely to enhance environmental performance, but few have been evaluated at the production system level, especially on grass-based cattle farms. This farming system is important in temperate regions, where most of the world’s bovine products are produced (Opio *et al.*, 2013).

For the purpose of the current study, pasture-based production of dairy and beef is defined as a system within which cattle graze freely outdoors on green pasture for at least 6 months of the year, using grass as the primary feed source (Läpple *et al.*, 2012). This type of production is possible in temperate maritime/oceanic climates where grass grows for most of the year, and is predominant in Ireland and New Zealand, in addition to being widely practised throughout the UK.

## 1.1 Objectives

The CattleDiVersa project provides a robust evidence-based approach for the design and communication of diversification tools that could be implemented on Irish beef and dairy farms, to reduce their environmental impact.

The project comprises six work packages (WPs) (Figure 1.1). In WP2, a detailed analysis was conducted of studies of pro-environmental diversification from Ireland, the UK and New Zealand, three countries that are highly dependent on grass-based production of milk and beef. The project also aimed to understand the experiences of farmers who have already implemented pro-environmental diversification on their farms. The actions taken to diversify were also identified. This was done by carrying out case studies of farms led by Irish, UK and French farmers where diversification has already been implemented (WP3). By conducting a survey (WP4), attitudes among farmers and behavioural barriers to implementing diversification activities on their farms were explored and defined. In WP5, a life cycle assessment (LCA) of pasture-based beef and dairy production was provided for three diversification options: mixed grass–white clover (GWC) swards, organic farming (OGF) and agroforestry (AFS). Short video-clips presenting pro-environmental diversification on Irish and UK farms were prepared (WP6).

Finally, recommendations for governmental support and improved legislation that will encourage systemic change in this area have been provided.

## 1.2 Layout of the Report

The layout of the report is as follows:

- In Chapter 2, we explore Irish, UK and French farmers’ subjective experiences of pro-environmental diversification, which, inevitably,

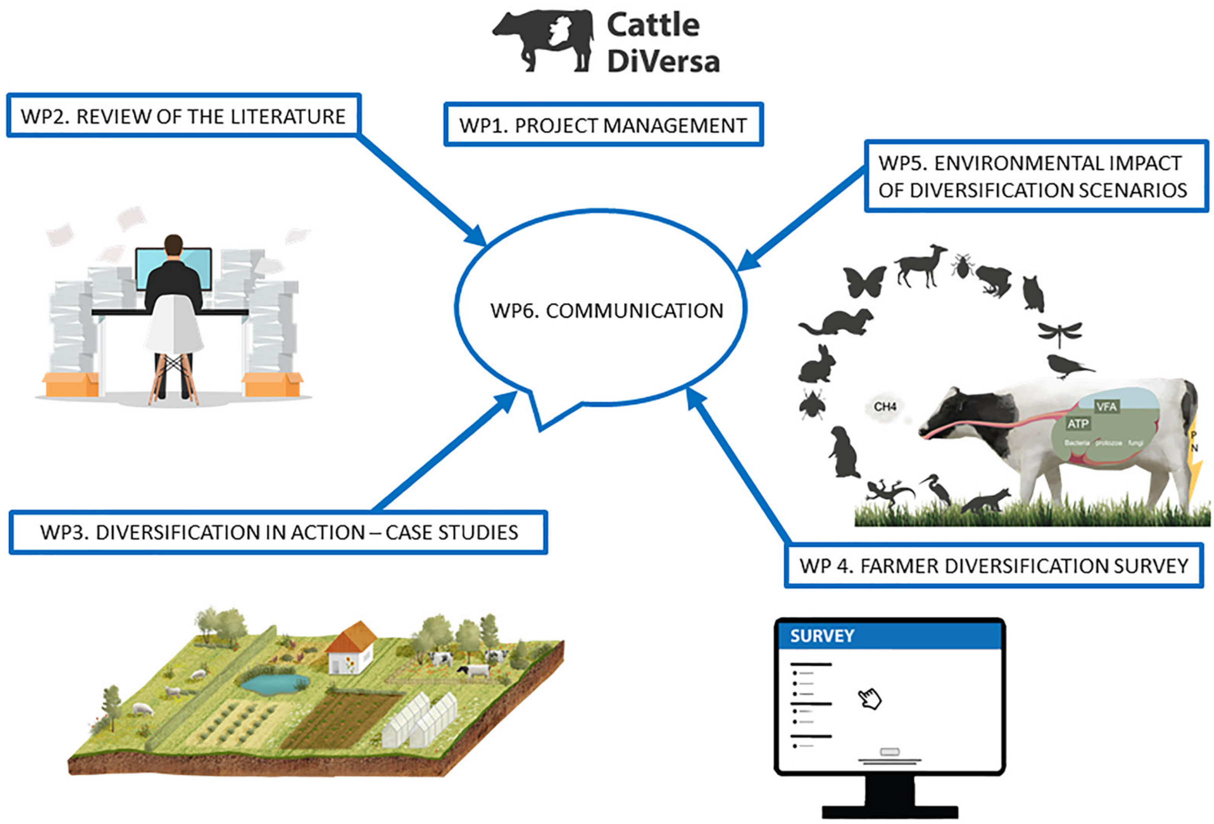


**Figure 1.1. Overview of the study components.**

were shaped by their biographical stories; how they made meaning from events in their lives; and the values shaped by these events that influenced their choices to consider and implement pro-environmental diversification.

- In Chapter 3, we focus on pro-environmental activities implemented by interviewed farmers. Chapter 3 also presents the main findings of the scoping literature review.
- Chapter 4 presents the results of a nationwide survey of Irish beef and dairy farmers, which allowed us to establish the determinants of farmers' behaviours and beliefs that relate to pro-environmental agriculture. This survey aimed to help better measure and conceptualise beef and dairy farmers' attitudes towards specific diversification activities on their farms. This investigation sought to answer the following questions: (1) To what extent do beef and dairy farmers' attitudes towards diversification opportunities lead to the increased adoption of environmentally sustainable agriculture and reduced GHG emissions? (2) What factors influence such beliefs? (3) What might motivate farmers to increase the uptake of such opportunities in the future? In responding to these questions, it is envisaged that this survey can assist policymakers in addressing how to work with farmers, for farmers and for nature.
- Chapter 5 presents the environmental impact of three diversification options recommended for livestock farms: GWC swards, OGF and AFS. The options were applied to dairy and beef production (suckler calf to beef farming) systems common in Ireland. Both of these bovine systems were evaluated over a 3-year period (2017–2019) and were nationally representative. The environmental impact and resource use of dairy and suckler calf to beef systems were modelled using LCA.
- Finally, Chapter 6 summarises the study findings and presents the primary conclusions and recommendations for future work.

# 2 Characteristics of Farmers Who Implement Pro-environmental Diversification on Their Farms

## 2.1 Materials and Methods

### 2.1.1 *Study design and interviewee selection*

The overarching study design adhered to a case study approach, involving in-depth, biographical interviews with professionals undertaking a predefined activity – pro-environmental diversification. In the current study, participants comprised 29 active farmers from Ireland ($n = 15$), the UK ($n = 7$) and France ($n = 7$) who characterised themselves as pro-environmental farmers (i.e. farmers actively implementing on-farm diversification activities beneficial to environmental remediation, biodiversity promotion and climate change mitigation and adaptation). The interview design was informed by the biographical narrative interpretive method – a qualitative interviewing technique used to induce a continual account of an interviewee's lived experience and discern attendant narrative and social nuances (Wengraf, 2006; Corbally and O'Neill, 2014).

### 2.1.2 *Interview questions*

The interview was based around a methodically formulated single question aimed at inducing narrative (SQUIN), according to Wengraf (2006). The SQUIN was worded as follows:

> I'm a researcher who is interested in farm diversification, climate change and the environment. Please tell me the story of your farming experience over the years, all the changes that you have seen and experiences that you have had; how it all has been.

### 2.1.3 *Respondent selection and data analysis*

The study aimed to interview innovative and pioneering farmers who had already implemented pro-environmental diversification on their farms. Thus, random sampling was not suitable for this study and interview participants were selected using a combination of convenience and purposive sampling. To qualify as eligible, prospective participants were required to have actively adopted pro-environmental agricultural diversification practices on their farms. To preserve anonymity and enable identification of interviewees, random case numbers were assigned to each participant prior to analysis.

Prior to the commencement of the study, a research ethics protocol was submitted to and approved by the Research Ethics Committee of the School of Agriculture and Food Science at University College Dublin (serial number: LS-20-52-Markiewicz). All study participants signed consent forms to be interviewed. Interviews were conducted by researchers trained in qualitative research methods and were carried out over 9 months (October 2020 to July 2021). The interviews were undertaken via Zoom due to physical restrictions imposed by the COVID-19 pandemic. All interviews were digitally recorded, transcribed verbatim and anonymised; the average interview length was 58 minutes.

As interviews comprised responses to a single open-ended question and case-dependent follow-up questions (based on respondents' narrative stories), transcripts inherently differed in thematic sequence. To enable data familiarisation and facilitate consistency in coding, active reading and re-reading of the transcripts were undertaken by two researchers. Interviews were analysed using NVivo 12 Plus qualitative data analysis software. Data analysis was conducted using thematic analysis in accordance with the criteria established by Braun and Clarke (2014).

## 2.2 Results

### 2.2.1 *Farmers' characteristics*

The average farm size was 68 ha for Ireland, 266 ha for the UK and 133 ha for France. The smallest farm (12 ha) was located in Ireland, while the biggest (440 ha) was located in the UK. Of the 29 respondents interviewed for the current study, 72% ($n = 21$) were certified organic farmers.

Approximately one-third of interviewed farmers (38%, $n = 11$) reported initiating their career in agriculture within the last 10 years (Table 2.1). With respect to farming background, 65.5% ($n = 19$) of respondents reported growing up on a family farm, while 34.5% ($n = 10$) reported being new entrants to farming. Of the 16 respondents who transitioned to pro-environmental farming from conventional/high-input farming, 81.3% ($n = 13$) reported a family background in farming.

### 2.2.2 *Motivations for diversifying*

Nine motivating factors encouraging transition towards or expansion of pro-environmental agricultural diversification were identified (Table 2.2). The most frequently cited motivating factor was environmental protection (96.6%, $n = 28$). Although a number of farmers cited climate change mitigation as a motivator (41.4%, $n = 12$), the subject was mentioned less often and was frequently treated as a secondary benefit to environmental protection and biodiversity promotion. In addition to environmental health and climate change mitigation, farmers also frequently cited biodiversity promotion (79.3%, $n = 23$), finance (79.3%, $n = 23$), ethical food production (72.4%, $n = 21$), quality of life (72.4%, $n = 21$) and social cohesion (72.4% $n = 21$) as motivations for implementing pro-environmental diversification.

**Table 2.1. Socio-demographic and farming characteristics of interview participants**

| Variable | Variable category | *n* (%) |
|---|---|---|
| Country | Ireland | 15 (51.7) |
| | UK | 7 (24.1) |
| | France | 7 (24.1) |
| Gender | Male | 19 (65.5) |
| | Female | 10 (34.5) |
| Age (years) | 26–35 | 3 (10.3) |
| | 36–45 | 8 (27.6) |
| | 46–55 | 9 (31.0) |
| | 56–65 | 5 (17.2) |
| | >66 | 4 (13.8) |
| Education | Junior certificate or GCSEs | 2 (6.9) |
| | Leaving certificate or A-levels | 2 (6.9) |
| | Higher certificate or diploma | 6 (20.7) |
| | Third-level bachelor's degree | 10 (34.5) |
| | Postgraduate degree, master's or PhD | 9 (31.0) |
| No. of years in farming | 1–10 | 11 (37.9) |
| | 11–20 | 5 (17.2) |
| | >20 | 13 (44.8) |
| No. of years in OGF | 1–10 | 10 (34.5) |
| | 11–20 | 4 (13.8) |
| | >20 | 7 (24.1) |

*Profitability*

Seventy-nine per cent of interviewed farmers talked about their farms' economic viability, and 66% mentioned that their income was not negatively affected by pro-environmental diversification. When outlining the financial benefits accrued by pro-environmental diversification, respondents focused primarily on provision of monetary grants for agri-environmental scheme participation and reduction of input costs. These benefits were given particular importance by organic beef farmers and farmers who originally practised high-input, intensive agriculture.

Almost 80% ($n = 23$) of farmers referred to a form of diversification of income streams that was distinct from agriculture-specific practices and added profitability to the farm. The activities cited most were on-farm food processing, direct sales, self-catering and farm tours. Irish participants also recognised the profitability of having some part of the land in forestry as a good investment and a starting point for their heirs.

Having off-farm employment was mentioned by 24% of participants (i.e. five farmers from Ireland and two farmers from the UK). Farmers who had off-farm employment felt that it gave them an advantage over other farmers. They perceived extra income as a tool to obtain financial security and means that allowed them to take more risk when implementing innovations.

A significant proportion of farmers (75.9%, $n = 22$) mentioned having at least one skill distinct from agriculture, such as construction, engineering, food production and marketing. These respondents readily identified examples of knowledge transfer in recounting their diversification measures, indicating that upskilling was vital in the implementation of pro-environmental agriculture.

**Table 2.2. Motivations for pursuing pro-environmental agricultural diversification by farmer country**

| Motivation | Farmer location (%) | | | |
|---|---|---|---|---|
| | France (*n* = 7) | Ireland (*n* = 15) | UK (*n* = 7) | Total (*n* = 29) |
| Environmental protection | 7 (100.0) | 14 (93.3) | 7 (100.0) | 28 (96.6) |
| Biodiversity promotion | 6 (85.7) | 12 (80.0) | 5 (71.4) | 23 (79.3) |
| Finance | 5 (71.4) | 13 (86.7) | 5 (71.4) | 23 (79.3) |
| Ethical food production | 6 (85.7) | 8 (53.3) | 7 (100.0) | 21 (72.4) |
| Quality of life | 6 (85.7) | 11 (73.3) | 4 (57.2) | 21 (72.4) |
| Social cohesion | 6 (85.7) | 10 (66.7) | 5 (71.4) | 21 (72.4) |
| Citizen education | 6 (85.7) | 8 (53.3) | 3 (42.9) | 17 (58.6) |
| Self-reliance | 5 (71.4) | 7 (46.7) | 4 (57.2) | 16 (55.2) |
| Animal welfare | 1 (14.3) | 9 (60.0) | 4 (57.2) | 14 (48.3) |
| Climate change mitigation | 2 (28.6) | 5 (33.3) | 5 (71.4) | 12 (41.4) |
| Political activism | 1 (14.3) | 4 (26.7) | 3 (42.9) | 8 (27.6) |

*Ethical food production*

In this study, ethical food production refers to food production that includes the consideration of people (workers' welfare), the environment (centred on environmental sustainability) and animals (mainly concerned with animal rights and welfare). In their narrative stories, 48% of farmers talked about their attitude towards the contemporary food system, while, for 72%, ethical food production was an important motivator to pursue pro-environmental agricultural diversification. Producing healthy, nutritious food for their families and the local community was an important motivation for many farmers. Interviewees often questioned conventional food production, in which farmers do not consume the food they produce and do not produce food for themselves. Being transparent, knowing their customers and giving customers the opportunity to visit the farm were mentioned as important aspects of producing food by 17 interviewees.

*Activism and social values*

An overall message that resonated among all participants was that farmers have a social responsibility to protect the environment. The strong need to transform the food system was also often linked with taking responsibility for the future of next generations.

Being conducive towards fostering community relationships via direct-to-consumer selling and citizen education was highly valued by farmers from France and Ireland. Being actively engaged in education and teaching activities to promote pro-environmental diversification was an important aspect for 15 farmers. Educational actions undertaken by the interviewees included formal and informal actions and were mostly centred on giving talks about their farms to visitors, participating in initiatives undertaken by local, national and international stakeholders and farmers associations (e.g. Farming for Nature), engaging with local media, creating knowledge transfer media showcasing nature-friendly farming methods and providing advice to other farmers.

*Input reduction and self-sufficiency*

The importance of input reduction was mentioned by 72% of interviewees. The benefits of input reduction were associated mostly with economic savings (44%) and benefits for the environment (41%). Reduction of inputs by the decreased or discontinued use of fertilisers, pesticides and concentrate feeds was mentioned by 44% of interviewees. Seven interviewees, of whom four were from France, talked about their efforts to decrease fossil fuel use and reduce their spending on machinery. Actions taken to achieve these goals included the reorganisation of farm work to use manual labour or machinery with reduced horsepower where possible. Reducing the frequency of tractor and other machinery usage has been recognised as an important means of decreasing fossil fuel consumption.

Self-sufficiency was an aspect mentioned as being important by 55% of farmers. Direct sales were given as an example of how farmers achieved self-sufficiency. All French farmers reported that they implemented direct sales in their business – in contrast to 43% of UK farmers and 29% of Irish farmers. Direct sales were realised by several channels, including farmers' markets, internet sales, on-farm stores/selling points and OGF networks. Interviewees cited several benefits of the direct sales model. Independence and being in control of prices were mentioned as major advantages.

Eighty-five per cent of Irish farmers, and 57% and 42% of French and UK farmers, respectively, shared their opinions about the lobbies and big companies. Farmers were of the opinion that chemical and processing industries represent a barrier to implementing pro-environmental diversification on a bigger scale. Participants mentioned that the processing industry puts considerable pressure on farmers in terms of the prices they pay, and farmers are always "the weakest end of the food chain". According to interviewees, big industry does not have an interest in looking for nature-based solutions that would reduce companies' sales. Participants talked about a "trap" in the conventional system in that the corporate system convinces farmers that they have to use external inputs to gain profit.

### *2.2.3 Challenges related to pro-environmental diversification*

Challenges related to pro-environmental diversification that were most often cited by interviewees were linked to rules and regulations, including rules that favour conventional agriculture, lack of information and labour intensiveness.

Changes in agricultural practices (e.g. farming without synthetic fertilisers and pesticides, the creation of small ecosystems in permaculture systems, changes associated with AFS) were mentioned as a major and difficult step in implementing pro-environmental diversification, and nature-inclusive actions such as creating wildlife habitats were often said to be accompanied by additional costs and, thus, were introduced gradually, being described as ongoing (Mooney *et al*., 2023). While farmers were generally receptive towards financially incentivised pro-environmental schemes and related policies, they were also concerned about existing ambiguities preventing full transparency and integrity of practice. Interviewees claimed that pro-environmental incentives could be exploited by farmers who still primarily practised intensive farming and failed to achieve important environmental metrics. Interviewees highlighted the idea of "green-washing" and the emergence of cynicism among pro-environmental farmers with regard to pro-environmental farming practices. There may be farmers who perform one-off actions to "tick the box", without implementing wider system changes. On the other hand, regardless of complex regulations, most organic farmers admitted that organic certification is the best way to guarantee quality to consumers (Mooney *et al*., 2023).

Issues surrounding land eligibility were mentioned alongside challenges relating to policy. Despite their passion for AFS, five interviewees from Ireland expressed their dissatisfaction with the current AFS scheme, which holds them back from taking action in expanding/establishing new AFS. The interviewees pointed out that the conversion of agricultural land to forestry is still not economically beneficial to farmers (Mooney *et al*., 2023).

Stigma and/or social inequality were referenced by over half of the farmers ($n = 17$). Interviewees claimed that doing things differently, i.e. implementing new farming practices, converting to an organic system and producing novel niche products, was often perceived negatively by the farming community. Referencing mainstream high-input dairy farming within the Irish agricultural sector, a farmer from Ireland noted that OGF was still viewed by many farmers as an undesirable niche practice. Another Irish farmer commented on the resistance of the official advisory body to OGF when he was considering the change (Mooney *et al*., 2023).However, the majority of farmers said that the opinions of others did not influence their decisions and they have been determined to prove that the nature-inclusive farming system they practise, albeit different from mainstream farming, can be profitable and productive (Mooney *et al*., 2023).

When examining the role of gender in farming, all women who took part in the interviews ($n = 10$) had either personally been the target of stigma or discrimination or knew of another woman farmer who had. However, views relating to the scale of this issue varied. For example, women in Ireland and the UK noted that they are broadly accepted within the farming community but are subjected to outdated views or perceptions (Mooney *et al*., 2023).

Nonetheless, almost half of the female respondents (40.0%, $n = 4$) mentioned discrimination by the media, which presents figures that mainly pertain to male farmers, and by regulatory bodies (Mooney *et al*., 2023).

# 3 Pro-environmental Diversification of Pasture-based Dairy and Beef Production: Diversification Possibilities in Irish Conditions

## 3.1 Methods

This chapter presents findings from the scoping literature review (Markiewicz-Keszycka *et al*., 2023) and from interviews with farmers, for which the methodology was described in Chapter 2. The literature review was performed in accordance with a methodological framework previously employed for several high-impact reviews (Arksey and O'Malley, 2005; O'Brien *et al*., 2016; Tricco *et al*., 2016; Andrade *et al*., 2018). The framework has five phases: (1) defining the research question(s); (2) identifying potentially relevant studies; (3) screening and selecting relevant literature; (4) extracting data and thematic analysis; and (5) synthesis of results and identifying research gaps.

The primary research questions were:

- What pro-environmental diversification approaches for grass-based dairy and beef production in Ireland, the UK and New Zealand have been presented in the scientific literature?
- What are beef and dairy farmers' attitudes towards pro-environmental diversification in these three countries?
- What research gaps and scientific challenges are associated with the diversification of grass-based dairy and beef production?

After defining research questions, relevant keywords were identified for searching and identifying potentially applicable studies on pro-environmental diversification of pasture-based dairy and beef production. A systematic search of published papers was conducted in Scopus and Web of Science and identified all relevant articles published up to 25 September 2020. The search was limited to peer-reviewed papers published in English between 1 January 2000 and 25 September 2020. Research papers that presented the impact of pro-environmental diversification on the environment and animal welfare and farmers' attitudes towards diversification were included in this review (Markiewicz-Keszycka *et al*., 2023).

## 3.2 Results

### *3.2.1 Results of literature review*

Overall, 39 articles were identified, of which 30 focused on pro-environmental options applied on dairy and/or beef farms and eight focused on the attitudes of dairy and beef farmers towards pro-environmental diversification, while one article covered both aspects. Detailed results of the literature review can be found in Markiewicz-Keszycka *et al*. (2023).

Studies describing pro-environmental measures available for use on dairy and beef farms were delineated into seven main themes: (1) environmentally sensitive management practices (ESMPs) – i.e. stubbles, patches of seed-rich crops, low-input grasslands, field margin management, hedge and ditch management, watercourse margin (riparian buffer) management and replacement of species-poor agricultural grassland with other plants; (2) multispecies swards (MSSs); (3) alternative farming systems – i.e. OGF; (4) grazing of semi-natural rough grasslands and species-rich grasslands; (5) mixed grazing; (6) AFS; and (7) rare/indigenous breeds (Markiewicz-Keszycka *et al*., 2023).

During thematic analysis, 12 distinct pro-environmental management practices potentially benefiting the environment, biodiversity or animal welfare when implemented on dairy and beef farms were distinguished (Table 3.1).

MSSs ($n=8$), ESMPs ($n=7$) and OGF ($n=7$) were the most frequently studied diversification options. Analysis of the impact(s) addressed by each diversification option are presented in Figure 3.1B and Table 3.1. Overall, 58% of identified articles in the "pro-environmental diversification" category focused on the impact of diversification on biodiversity ($n=18$), while 41% ($n=13$) concentrated on livestock performance (Figure 3.1B). However, no identified study addressed all five impacts (product quality, animal welfare, biodiversity, livestock performance and

**Table 3.1. Impact of different diversification measures on biodiversity and environment**

| Pro-environmental diversification | Factor | Impact | | Study |
|---|---|---|---|---|
| Stubbles[a] | Birds | + | Positive impact on the population growth rates of multiple granivorous species, i.e. corn bunting, goldfinch, linnet, grey partridge, reed bunting, skylark and yellowhammer | Peach *et al.*, 2011; Baker *et al.*, 2012 |
| | | +/– | No impact on farmland bird species | Davey *et al.*, 2010 |
| | | – | Negative impact on goldfinch | Baker *et al.*, 2012 |
| Patches of seed-rich crops[a] | Birds | + | Positive impact on multiple granivorous species, i.e. corn bunting, reed bunting, skylark, tree sparrow, yellowhammer | Baker *et al.*, 2012 |
| | | +/– | Lack of positive impact on farmland bird species | Davey *et al.*, 2010 |
| | | – | Negative impact on chaffinch and tree sparrow | Baker *et al.*, 2012 |
| Low-input grasslands (including heterogeneous swards)[a] | Birds | + | Positive impact on chaffinch, lapwing, linnet, skylark and yellow wagtail | Baker *et al.*, 2012 |
| | | +/– | Lack of positive impact on farmland bird species | Davey *et al.*, 2010 |
| | | – | Negative impact on chaffinch, lapwing, meadow pipit, reed bunting and yellow wagtail | Baker *et al.*, 2012 |
| | Plants | + | UGs contained multiple species of grasses, forbs and legumes, 59% of which were not found on other site types. Species richness on CGs was lower and covered 37% of the species found on UGs. As expected, improved grasslands included only a few species of plants and were dominated by ryegrass and clover | French, 2017 |
| | Nutritional quality | + | Forage from species-rich grasslands contained up to 27% more protein, 56% more P, 106% more potassium and 183% more calcium than cereals and conventional hay, and met the nutritional requirements of beef cattle, sheep and horses | French, 2017 |
| Field margin management (e.g. widening, input reduction 2–6 m adjacent to arable/pastoral field)[a] | Birds | + | Arable margins – positive impact on corn bunting, dunnock, linnet and turtle dove | Baker *et al.*, 2012 |
| | | | Grassland margins – positive impact on chaffinch, dunnock, greenfinch and whitethroat | |
| | | – | Arable margins – negative impact on bunting, goldfinch and yellow wagtail | |
| | | | Grassland margins – negative impact on corn bunting | |
| | Invertebrate | +/– | Lack of significant effect on carabid beetles | Feehan *et al.*, 2005 |
| | Plant species richness | +/– | Lack of significant effect on plant species richness | Feehan *et al.*, 2005 |
| | Invertebrate | +/– | Positive impact on several native spiders, pollinators and mite species | Curtis *et al.*, 2019 |
| | | | Negative impact on exotic slug species | |
| Hedge and ditch management[a] | Birds | + | Positive impact on bullfinch, house sparrow, reed bunting and song thrush | Baker *et al.*, 2012 |
| | | – | Negative impact on goldfinch, tree sparrow, yellowhammer | |
| | | +/– | Lack of positive impact on farmland bird species | Davey *et al.*, 2010 |
| | Plants | +/– | Lack of significant effect on plant species richness | Feehan *et al.*, 2005 |
| | Carabid beetles | +/– | Lack of significant effect on carabid beetles | Feehan *et al.*, 2005 |

**Table 3.1. Continued**

| Pro-environmental diversification | Factor | | Impact | Study |
|---|---|---|---|---|
| | Small mammals | + | Improved connectivity had a positive impact on wood mice abundance | Gelling *et al.*, 2007 |
| | | | Hedgerow gappiness had negative impact on bank voles | |
| | | | Increased hedgerow width, height and length had positive impact on all small mammals | |
| Water course margins (fencing)[a] | Plants | +/– | Lack of significant effect on plant species richness | Feehan *et al.*, 2005 |
| Replacement of species-poor agricultural grassland with other plants[a] | Invertebrate | + | Replacing grass with cereals and conservation mix attracted significantly more invertebrates than grass-based treatments. The conservation mix attracted more diverse bumblebees and butterflies than the under-sown spring cereal treatment | Potts *et al.*, 2009 |
| | Birds | + | Positive impact of barley crops on seed-eating birds | Peach *et al.*, 2011 |
| Mixed grazing | Birds | + | Positive impact on pipit territories | Evans *et al.*, 2006 |
| | $CH_4$ emissions | + | Estimated total emissions across the summer grazing period were expressed relative to the growth rates achieved – the sheep-only system was characterised by higher amounts of $CH_4$ per unit liveweight gain | Fraser *et al.*, 2014 |
| MSSs | N concentration in urine | + | Decreased N concentration in urine from cows fed mixtures containing herbs | Totty *et al.*, 2013; Box *et al.*, 2017; Bryant *et al.*, 2017; Minneé *et al.*, 2017; Dodd *et al.*, 2019 |
| | | +/– | No effect on urinary N after adding chicory or plantain to ryegrass/white clover swards | Cheng *et al.*, 2018 |
| | $CH_4$ emissions | +/– | Adding lucerne, chicory and plantain to ryegrass/white clover swards did not change $CH_4$ emissions | Jonker *et al.*, 2019 |
| | | + | Decrease in daily $CH_4$e production from cattle consuming a ryegrass–wildflower mixture | Hammond *et al.*, 2014 |
| SNRG vs PP grazing | Birds<br>Insects | + | Introduction of cattle to SNRG had positive impact on the abundance of birds and butterflies | Fraser *et al.*, 2013, 2014 |
| | Plants | + | SNRG increased plant diversity on marginal land | |
| Replacement of modern crossbred cattle with a traditional breed | Birds<br>Insects | +/– | No impact on birds and butterflies | Fraser *et al.*, 2014 |
| | $CH_4$ emissions | – | Negative impact | |
| Organic vs conventional farming | Plants | + | Positive impact on total number of plant species | Gabriel *et al.*, 2010; Power and Stout, 2011; Power *et al.*, 2012, 2013 |
| | | +/– | Number of insect taxa | Gabriel *et al.*, 2010; Power and Stout, 2011 |
| | Insects | + | Positive impact on bee abundance and evenness, and hoverfly evenness | |
| | | +/– | Bee richness; hoverfly abundance and richness | |
| | Birds | - | Diversity of farmland birds | |

**Table 3.1. Continued**

| Pro-environmental diversification | Factor | Impact | | Study |
|---|---|---|---|---|
| AFS | Water quality | + | Decrease in sediment export (by 76%), P loss (by 62%) and faecal coliform levels (by 43%) | Dodd *et al.*, 2008 |
| | | | The aquatic fauna indicator also showed a positive trend and increased to 82% from 78% pre-change | |
| | Plant | + | Plant diversity on the pastures significantly increased | |
| | Soil | + | Poplar pastures had higher pH and produced more throughout 11 months than open pastures | Guevara-Escobar *et al.*, 2002 |
| | | +/– | No effect on organic C, total N, P, sulphur, soil hydraulic characteristics, microporosity, water aggregate stability and bulk density | |

**[a]Actions identified as ESMPs.**

**C, carbon; CG, conservation grassland; P, phosphorus; PP, permanent pasture; SNRG, semi-natural rough grazing; UG, unimproved grassland.**



the environment), while only studies on OGF examined impacts on animal welfare (Markiewicz-Keszycka *et al.*, 2023).

### 3.2.2 Diversification possibilities in Irish conditions

*Environmentally sensitive management practices*

During the literature review process seven ESMPs were identified (Table 3.1), with boundary (ditches and hedgerow) management the most frequently studied ESMP ($n=4$). Five articles (Feehan *et al.*, 2005; Potts *et al.*, 2009; Peach *et al.*, 2011; Baker *et al.*, 2012; Curtis *et al.*, 2019), three from the UK and one each from New Zealand and Ireland, investigated the impact of field margins ($n=3$) and replacement of grassland with other plant species ($n=2$) on biodiversity. The impacts of individual ESMPs on biodiversity are summarised in Table 3.1. The results of the interviews conducted with the farmers who already implemented pro-environmental diversification on their farms indicate that ESMPs were widely used by this cohort of farmers, with boundary management and pond establishment mentioned most frequently (Figure 3.2).

*Multispecies swards*

Seven studies conducted in New Zealand and one conducted in the UK focused on utilising MSSs for dairy production. The main studied aspects were associated with the effects of MSSs on livestock performance, milk production/composition and nitrogen (N) excretion. Plant species most frequently added to researched swards included plantain ($n=7$) and chicory ($n=5$), with one study (Hammond *et al.*, 2014) examining the effects of a wildflower mixture. Even though MSSs by their nature increase diversity of plants and potentially encourage more biodiversity on the farm, this factor has not been studied in identified papers. The environmental impacts of MSSs on urinary N excretion and methane ($CH_4$) emissions are summarised in Table 3.1 (Markiewicz-Keszycka *et al.*, 2023).

The results of the interviews indicate that the establishment of MSSs was mentioned as an important diversification measure by 60% of Irish farmers, 42.86% of UK farmers and 14% of French farmers (Figure 3.3). The interviewees indicated that MSSs add resilience for summer droughts, reduce the need for fertilisers, provide better nutrition for livestock, have anthelmintic properties, attract pollinators and reduce input costs (Mooney *et al.*, 2023). Farmers indicated that their multispecies mixtures contained between 9 and 20 species of grasses, legumes and herbs, with red clover, plantain, chicory, yarrow, meadow fescue and timothy being mentioned most often. Other plant species included in the swards were burnet, oregano, white clover, sorrel, *Cecilia* and bird's foot trefoil.

*Organic farming*

Seven studies of OGF on dairy farms were identified – four from the UK and three from Ireland. Three studies

Heat map A

| Diversification | Country | | |
|---|---|---|---|
| | New Zealand | Republic of Ireland | United Kingdom |
| ESMP | 1 | 1 | 5 |
| Mixed grazing | 0 | 0 | 4 |
| Multispecies swards | 7 | 0 | 1 |
| Organic farming | 0 | 3 | 4 |
| Rare breeds | 0 | 0 | 3 |
| SNRG | 0 | 0 | 5 |
| Inclusion of trees | 2 | 0 | 0 |
| **Attitudes** | | | |
| Afforestation and energy crops | 0 | 3 | 3 |
| Organic farming | 0 | 3 | 0 |
| **Total number of papers** | 10 | 10 | 25 |

Heat map B

| Diversification | Impact | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Product quality | Animal welfare | Biodiversity | | | | | Livestock Performance | | | Environment | | |
| | | | Biodiversity total | Birds | Invertebrates | Plants | Small Mammals | Total Livestock Performance | Beef | Dairy | Soil | Water | GHG |
| ESMP | 0 | 0 | 7 | 4 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mixed Grazing | 6 | 0 | 4 | 2 | 1 | 2 | 0 | 3 | 3 | 0 | 0 | 0 | 1 |
| Multispecies Swards | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 8 | 0 | 0 | 8 |
| Organic Farming | 0 | 3 | 4 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rare breeds | 1 | 0 | 2 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | | 1 |
| SNRG | 1 | 0 | 3 | 1 | 1 | 2 | 0 | 3 | 3 | 0 | 0 | 0 | 2 |
| Inclusion of trees | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 |
| **Total number of papers** | 7 | 3 | 18 | 7 | 7 | 9 | 1 | 13 | 5 | 8 | 2 | 1 | 10 |

**Figure 3.1. Heat maps displaying frequency of diversification measures and attitudes by country (A) and their impact on product quality, animal welfare, biodiversity, livestock performance and the environment (B). Colours and numbers correspond to number of papers identified. Reproduced from Markiewicz-Keszycka *et al*. (2023); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).**


**Figure 3.2. Examples of ESMPs. (A) Hedge management; (B) wildflower field margin; (C) pond; and (D) patches of seed-rich crops.**

**Figure 3.3. Examples of MSSs established by interviewees.**

explored the impact of organic agriculture on animal welfare, with four focusing on biodiversity (Markiewicz-Keszycka *et al.*, 2023). Results indicate that animal welfare was generally higher on organic farms than on conventional farms (Table 3.2). Cows on organic farms also had a lower culling rate due to health problems and experienced fewer pre-identified health-related issues than cows on non-organic farms (Langford *et al.*, 2009). Moreover, Kilbride *et al.* (2012) reported that participation in organic certification schemes significantly reduced the risk of non-compliance with animal welfare regulations (see also Langford *et al.*, 2009).

All studies examining the impact of OGF on biodiversity ($n = 4$) reported significantly higher plant diversity than that found on conventional farms, with positive impacts on insect abundance and evenness also described (Gabriel *et al.*, 2010; Power *et al.*, 2012, 2013). Gabriel *et al.* (2010) explored the impacts

**Table 3.2. Animal welfare indicators for organic and conventional farms**

| Indicator | Farm | | *p*-value | Study |
|---|---|---|---|---|
| | Organic | Non-organic | | |
| Age (months) heifers first calve | 27.3 | 25 | $<0.05$ | Langford *et al.*, 2009 |
| Time (days) calves spend with dams | 2.4 | 1 | $<0.05$ | Langford *et al.*, 2009 |
| Percentage of cows culled with reference to health records | 19.6 | 26.3 | $<0.01$ | Langford *et al.*, 2009 |
| Most common culling reason | Infertility, foot problems, mastitis | | – | Langford *et al.*, 2009 |
| Cases of endometritis in 1 year (% herd), with reference to health records | 6.1 | 10.8 | 0.05 | Langford *et al.*, 2009 |
| Cases of milk fever in 1 year (% herd), with reference to health records | 7.8 | 14.9 | 0.05 | Langford *et al.*, 2009 |
| Percentage of herd affected by lameness | 36.5 | 31.9 | NS | Langford *et al.*, 2009 |
| | Lower | Higher | 0.012 | Rutherford *et al.*, 2009 |
| Grazing intensity (mean LU/ha[a]) | 1.5 | 2.5 | – | Power *et al.*, 2013 |

**[a]Livestock unit per hectare.**

**NS, not significant.**



of land use at multiple spatial scales (field level to regional) on biodiversity, with biodiversity surveys indicating a higher abundance of plants, arthropods and butterflies in both organic fields and organic “hot-spots” (i.e. >15% of available land used for OGF) than in conventional plots or organic “cold-spots” (<5%).

Converting to OGF was often indicated as an important step in the diversification process by interviewees who took part in the CattleDiVersa study. Of the 29 respondents interviewed for the current study, 79.3% ($n=23$) identified as organic farmers (Mooney *et al.*, 2023).

### *Mixed and semi-natural rough grazing and rare breeds*

Seven studies on mixed grazing ($n=4$) and semi-natural rough grazing (SNRG; $n=5$) were identified in the literature review, with two studies researching the implementation of both practices. Out of seven studies, only two explored the combined impact of SNRG and mixed grazing on animal performance, and just one study investigated the effect of SNRG on meat quality (Markiewicz-Keszycka *et al.*, 2023). All studies originated from the UK. The impacts of mixed grazing and SNRG on biodiversity and environment are presented in Table 3.1.

The utilisation of rare breeds was explored in three studies from the UK (Fraser *et al.*, 2009, 2013, 2014) and focused on the performance of Belted Galloway and Welsh Black cattle, and their impact on birds and insects and $CH_4$ emissions (Table 3.1).

Interviewees who took part in the CattleDiVersa study often referred to conservation grazing instead of SNRG. Conservation grazing was practised by 24% of farmers (one farmer from France, two farmers from Ireland and four from the UK). By its nature, conservation grazing was practised by those who had access to the natural reserves, high-nature value land or marginal land, such as sand dunes, heathland and difficult to access hills. All Irish and UK participants described the benefits of livestock introduction to the environment and their role in maintaining healthy, balanced ecosystems (Mooney *et al.*, 2023).

According to the narrative stories told in the interviews, all conservation grazing was done by local rare breeds of cattle (Red Poles, Belted Galloway, Highland Cattle and Riggit Galloway in the UK, Dexters and Galloway Cattle in Ireland, and Rouge des prés in France), sheep (Manx Loaghtans and Hebrideans in the UK) and ponies (no details were provided about particular breeds, only that they were native) (Mooney *et al.*, 2023).

However, local rare breeds of livestock were also used/intended to be used by farmers who did not engage with delivering conservation grazing ($n=8$) (Figure 3.4). Cattle breeds raised by this group of farmers included Aberdeen Angus, Irish Moiled, Shorthorns and Highland. In addition, participants mentioned that they use rare breeds to crossbreed

**Figure 3.4. Conservation grazing by rare and native breeds.**

with more conventional breeds to get animals that would be well suited for their farm. Multiple attributes of these breeds, including good temperament, low weight (important for heavy, wet soils), good winter coating, longevity, sturdiness, low input and easy calving, were described by the participants (Mooney *et al*., 2023).

*Tree plantation and agroforestry*

Two studies from New Zealand examined inclusion of trees on cattle farms (Markiewicz-Keszycka *et al*., 2023). It was reported that land-use change and integration of trees onto farmland resulted in several economic and environmental benefits, including improved water quality characterised by a significant decrease in sediment export (–76%), phosphorus (P) loss (–62%) and faecal coliform levels (–43%). In addition, plant diversity within pastures significantly increased (+25%) (Dodd *et al*., 2008). Further results indicate that the inclusion of trees in pastures increased their productivity, accelerated soil formation and decreased erosion (Guevara-Escobar *et al*., 2002).

Tree plantation was considered one of the most effective forms of pro-environmental diversification on the farm, and, as such, it was mentioned by 79% of interviewees (Mooney *et al*., 2023). Management and establishment of hedgerows, AFS and plantation of orchards and forests were the main activities associated with trees (Figure 3.5).

Fourteen interviewees indicated their enthusiasm for hedgerow management and/or the need for the establishment of new hedges on their farm. AFS was considered a very efficient solution to increase a farm's productivity and decrease the environmental impact of animal production, also mentioned by 14 interviewees (Mooney *et al*., 2023).

Afforestation was described as an important on-farm activity, especially in Ireland ($n=4$), where forest cover is relatively low, at 11%, compared with the European Union average, at 39%. All interviewees who planted a forest stressed the significance of planting polycultures, especially in the context of the current risk from Chalara ash dieback (*Hymenoscyphus fraxineus*) in Europe, which causes a chronic fungal disease of ash trees (Figure 3.6) (Mooney *et al*., 2023).

*Other pro-environmental activities not included in the literature review*

Other pro-environmental practices mentioned by interviewees but not identified during literature search include regenerative agriculture, permaculture, mob

**Figure 3.5. Examples of animals under AFS.**

**Figure 3.6. Afforestation and incorporation of fruit trees on Irish farms.**

grazing (also known as holistic grazing, which requires longer rotation of the pastures, allowing grass to recover fully) and production of flowers, honey, fruits and vegetables (Figure 3.7).

Several organic farmers commented that OGF does not focus enough on soil regeneration and self-sufficiency of the ecosystems and that its intensification can pose a threat to the sustainability of this system. The importance of soil health was frequently mentioned by those who talked about regenerative agriculture ($n=7$), and the significance of restoring fertility was an important aspect for 17 interviewees, of whom four were not organic farmers (Mooney *et al.*, 2023).

Interviewees talked about their experiences in improving soil biology, structure and carbon sequestration. Protecting microbial communities in the soil, reduction or cessation of the usage of artificial fertilisers, herbicides and pesticides, no-till farming, the establishment of MSSs and mob grazing; plantation of

**Figure 3.7. Production of vegetables, honey and flowers as an example of pro-environmental diversification.**

trees; fermentation and dilution of raw slurry, chopping and incorporating straw into the soil after harvest, and use of lighter machinery and bale grazing in winter (to avoid using tractors on wet pasture) were recognised as reliable actions that improve soil health. Moreover, the capacity to sequester carbon (C) by improving soil quality has also been recognised as an important aspect.

# 4 Irish Beef and Dairy Farmers' Attitudes Towards Pro-environmental Diversification and Climate Crisis – Report on the Survey

## 4.1 Methodology

### *4.1.1 Survey design*

The survey was informed by a prior scoping review and qualitative questionnaire examining farmers' decisions to pursue pro-environmental agriculture. Final survey development was preceded by a pilot study to refine the length of the survey, its structure and question phraseology. Survey structure and question types were formulated in accordance with the *theory of planned behaviour*, which posits that behavioural adoption is modulated by intention, perceived behavioural control and beliefs. The theory of planned behaviour has been adopted extensively in quantitative investigations of farmers' decision-making and was thus adjudged to represent a broad, relevant point of reference for the current study.

The developed survey comprised 30 questions. Six questions focused on respondents' background characteristics (socio-demographics, farm type, farm size and herd size). Seven questions considered farmers' behaviours, with five retained for analysis (Table 4.1). Ten questions variously measured respondents' beliefs on climate change, the benefits of pro-environmental agriculture (e.g. economic, societal) and biodiversity loss. Questions concerning motivations for pursuing pro-environmental farming required respondents to rate the importance of on-farm environmental health, climate change and animal welfare, as well as market prices for organic products.

To qualify as eligible for survey participation, respondents were required to be aged ≥ 18 years, reside in Ireland and practise dairy and/or beef farming.

### *4.1.2 Survey scoring protocol*

A scoring protocol was developed for farmers' beliefs to measure respondents' favourability towards pro-environmental farming. Protocol development was used to simplify latent (cognitive) variables during statistical analysis and adhere to the theory of planned behaviour. Listwise deletion was undertaken where data were missing for one or more variable response categories, to ensure scoring accuracy.

The scoring protocol was based on 10 questions (Table A1.1). Ordinal scoring based on responses to Likert scale questions (0–2) was utilised to rate respondents' overall beliefs about pro-environmental farming. The maximum possible score for pro-environmental behaviours was 20, with scores standardised between 0 and 100 for statistical analyses.

### *4.1.3 Survey completion and analysis*

The survey was uploaded to the survey-hosting platform Qualtrics and made publicly available from 13 January to 7 April 2021. All prospective participants were informed of the study objectives and data handling protocols prior to commencing the survey,

**Table 4.1. Pro-environmental diversification actions**

| Variable | Response categories |
|---|---|
| OGF | Yes/no |
| Agri-environmental scheme involvement[a] | Yes/no |
| Adoption of pro-environmental land management measures[b] | Yes/no |
| Planting of trees/hedgerows | Yes/no |
| Use of low-emission fertilisers | Yes/no |

**[a]Agri-environmental schemes include the Agri-Environment Options Scheme, the Green Low-Carbon Agri-Environment Scheme (GLAS), OGF schemes, forest environmental protection schemes, sustainable forest management system schemes and European Innovation Partnership for Agriculture Productivity and Sustainability schemes.**

**[b]Land management measures include land set aside for pro-environmental activities, erosion management to combat landslide, increased areas for wildlife habitats, buffer strips to combat agricultural run-off into waterways and implementation of AFS.**

with respondents' ID and IP addresses excluded from the survey.

Survey data were imported to IBM SPSS Statistics 26 for analysis. Descriptive statistical functions were employed to detect outliers in continuous data (i.e. behaviour scores, motivation scores, farm size and herd size) and tested for statistical normality. Outliers were detected based on the interquartile rule, with the Shapiro–Wilk test used to determine data normality. Cronbach's alpha test was used to evaluate scored variables, to determine internal consistency.

Chi-squared tests were used to assess relationships between respondent demographics, farm characteristics and key behavioural and attitudinal variables concerning pro-environmental farm diversification. Mann–Whitney *U* and Kruskal–Wallis non-parametric tests were used where independent variables were continuous (i.e. scale format). The default significance level was set to 5% ($p < 0.05$) by convention. Binary logistic regression was employed to identify factors with the greatest predictive power pertaining to adoption of organic agriculture. Explanatory variables used for regression modelling were examined for statistical significance using the Wald statistic. The Hosmer–Lemeshow test was used to evaluate goodness-of-fit between observed and predicted cluster membership (Paul *et al.*, 2013).

## 4.2 Results

### *4.2.1 Respondent characteristics*

The survey was started by a total of 673 eligible respondents and completed in full by 378 respondents (a completion rate of 56.2%). The socio-demographic and farm characteristics of survey participants are presented in Table 4.2. Most respondents were male (87.9%, $n = 437$) and a large number reported acquisition of a third-level educational qualification (85.1%, $n = 418$). The modal age range of respondents was 36–45 years. Over half of the respondents reported farming beef (52.9%, $n = 356$), with 30.2% ($n = 203$) farming dairy and 16.9% ($n = 114$) farming both beef and dairy. Farm size (acres) and herd size (dairy cows and/or bullocks) were reported by 584 and 581 respondents, respectively; mean farm size was 176 acres (71 ha; standard deviation (SD) ± 125.8 acres) and mean herd size was 138 cattle (SD ± 110.2).

The age, herd size and educational level data given by the respondents differ from data reported in the Annual Review and Outlook for Agriculture, Food and the Marine (2022) and AgCensus (2020), which indicate that the average age of dairy and beef farmers is 52 and 58, respectively, while the average herd size is 66 cattle. This might be due to the CattleDiVersa

**Table 4.2. Socio-demographic and farm characteristics of survey respondents ($n = 673$)**

| Variable | Total answers, *n* | Category | Frequency, *n* (%) |
|---|---|---|---|
| Gender | 497 | Male | 437 (87.9) |
| | | Female | 60 (12.1) |
| Age (years) | 504 | 18–25 | 44 (8.7) |
| | | 26–35 | 89 (17.7) |
| | | 36–45 | 154 (30.6) |
| | | 46–55 | 127 (25.2) |
| | | 56–65 | 68 (13.5) |
| | | ≥66 | 22 (4.4) |
| Education | 491 | Primary/secondary school | 87 (17.7) |
| | | University/vocational degree | 331 (67.4) |
| | | Postgraduate degree, master's or PhD | 73 (14.9) |
| Farming type | 673 | Beef | 356 (52.9) |
| | | Dairy | 203 (30.2) |
| | | Beef and dairy | 114 (16.9) |

project using an online survey method, and thus being able to reach younger respondents with a higher educational level. This limitation will be addressed in our future studies on the subject.

### 4.2.2 Pro-environmental diversification behaviours

Of the respondents who reported their farming status, 8.2% (*n* = 49) claimed to already farm organically (Table 4.3). Half of the respondents (50.0%, *n* = 274) specifying their involvement in an agri-environmental scheme confirmed that they were currently involved with an existing scheme. A large proportion of respondents cited the adoption of pro-environmental land management measures (83.7%, *n* = 426), with most respondents also reporting the use of low-GHG-emission fertilisers, such as protected urea and slurry spreading, and using low-emission spreading methods (65.1%, *n* = 329) (Table 4.3).

The agri-environmental scheme with the greatest reported involvement among respondents was the Green Low-Carbon Agri-Environment Scheme (GLAS). While over 40% (*n* = 226) of respondents reported membership in the GLAS scheme, involvement with other agri-environmental schemes was markedly lower. Less than 10% (*n* = 43) of respondents reported participating in an organic scheme, with the lowest involvement recorded for forest protection schemes (1.6%, *n* = 9) and sustainable forest management schemes (2.2%, *n* = 12).

The provision of increased area for habitat creation (e.g. wildflower strips, hedges and field margins) was the most frequently cited pro-environmental land measure adopted by respondents (62.1%, *n* = 316) (Figure 4.1). The least cited measures were implementation of AFS (9.4%, *n* = 48) and erosion management to combat agricultural run-off (7.5%, *n* = 38).

**Table 4.3. Pro-environmental diversification actions**

| Variable | Total answers, *n* | Response categories | Frequency, *n* (%) |
|---|---|---|---|
| OGF | 598 | Yes/no | 49 (8.2) |
| Agri-environmental scheme involvement | 548 | Yes/no | 274 (50.0) |
| Land management measures | 509 | Yes/no | 426 (83.7) |
| Planting of trees/hedges | 507 | Yes/no | 373 (73.6) |
| Use of low-emission fertilisers | 505 | Yes/no | 329 (65.1) |

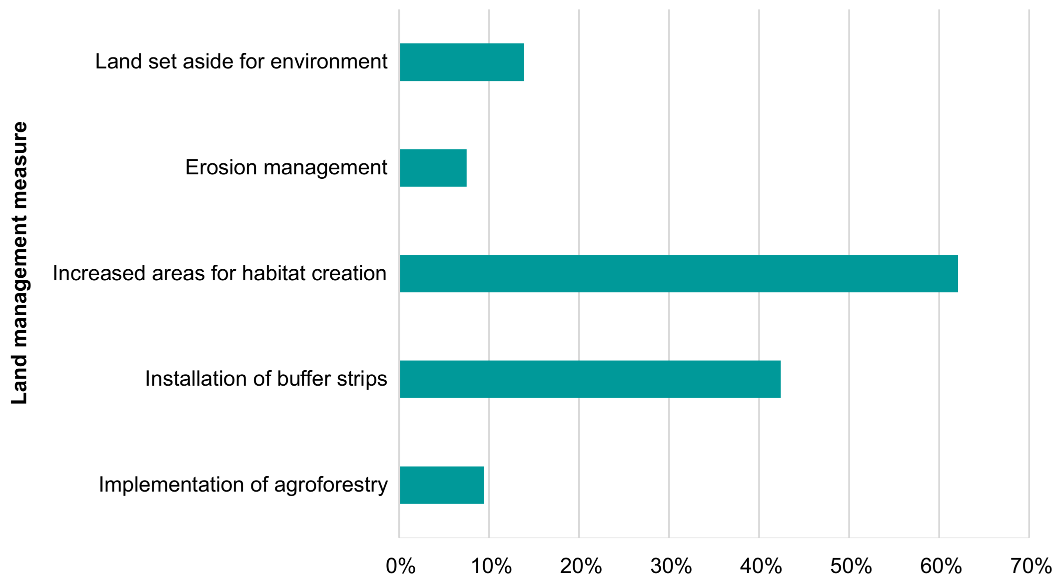


**Figure 4.1. Reported adoption of pro-environmental land management measures by survey respondents.**

### *4.2.3 Pro-environmental diversification beliefs and motivations*

Over half of the respondents believed that pro-environmental diversification would probably have a positive impact on Irish farming's international reputation (56.5%, *n* = 265) and would be unlikely to lead to reduced food production (50.1%, *n* = 230) (Table 4.4). Regarding economic concerns, however, over half of the respondents believed that pro-environmental farming would probably lead to less money for farmers (57.2%, *n* = 270) and would be unlikely to result in an improved overall economy

**Table 4.4. Pro-environmental beliefs among Irish livestock farmers (*n* = 505)**

| Variable | Total answers, *n* | Response category | Frequency, *n* (%) |
|---|---|---|---|
| I believe that environmentally friendly farming will lead to less money for farmers | 472 | Likely | 270 (57.2) |
| | | Neither likely nor unlikely | 59 (12.5) |
| | | Unlikely | 143 (30.3) |
| I believe that environmentally friendly farming will lead to an improved economy | 465 | Likely | 96 (20.6) |
| | | Neither likely nor unlikely | 109 (23.4) |
| | | Unlikely | 260 (55.9) |
| I believe that environmentally friendly farming will lead to a better society | 465 | Likely | 168 (36.1) |
| | | Neither likely nor unlikely | 88 (18.9) |
| | | Unlikely | 209 (44.9) |
| I believe that environmentally friendly farming will lead to a better international reputation for farming | 469 | Likely | 265 (56.5) |
| | | Neither likely nor unlikely | 135 (28.8) |
| | | Unlikely | 69 (14.7) |
| I believe that environmentally friendly farming will lead to less food for everyone | 459 | Likely | 157 (34.2) |
| | | Neither likely nor unlikely | 72 (15.7) |
| | | Unlikely | 230 (50.1) |
| I believe it is possible to farm and protect the environment at the same time | 550 | Agree | 522 (94.9) |
| | | Neither agree nor disagree | 21 (3.8) |
| | | Disagree | 7 (1.3) |
| As a farmer, I consider myself to be a guardian of the countryside | 512 | Agree | 499 (97.5) |
| | | Neither agree nor disagree | 6 (1.2) |
| | | Disagree | 7 (1.4) |
| I believe that agriculture contributes to a reduction in native wild plants | 505 | Agree | 284 (56.2) |
| | | Neither agree nor disagree | 89 (17.6) |
| | | Disagree | 132 (26.1) |
| I believe that a decrease in pollinating insects such as bees will have an impact on my farm | 505 | Agree | 303 (60.0) |
| | | Neither agree nor disagree | 134 (26.5) |
| | | Disagree | 68 (13.5) |
| I consider the issue of climate change to be | 500 | Important | 360 (72.0) |
| | | Moderately important | 101 (20.2) |
| | | Unimportant | 39 (7.8) |

(55.9%, $n = 260$). Over two-thirds of farmers (72.0%, $n = 360$) said that they believe that climate change constitutes an important issue with respect to farming.

Most respondents assigned importance to creating a healthier on-farm environment (81.4%, $n = 149$), but a considerably smaller proportion considered climate change mitigation (29.6%, $n = 53$) and improvement of animal welfare (34.6%, $n = 63$) as important motivators. Over half of the respondents (55.6%, $n = 104$) considered higher market prices for organic products an important motivation to farm organically (Table 4.5).

### *4.2.4 Barriers to pro-environmental behaviours among Irish farmers*

Overall, 515 respondents highlighted one or more principal barriers to increasing their adoption of pro-environmental agriculture. The most frequently cited barrier was a lack of well-established "know-how" (37.9%, $n = 195$), with a similar proportion of farmers also citing lower profit margins associated with pro-environmental farming (36.1%, $n = 186$). Of 91 respondents with a limited interest in planting more trees, the most frequently selected disincentives were prioritisation of animal production (25.3%, $n = 23$) and land area concerns (28.6%, $n = 26$). Of 434 farmers who did not rule out planting more trees on their farms, over half (52.1%, $n = 226$) selected greater financial incentives as a principal motivating factor for increasing their farm tree cover. The proportions of farmers who prioritised improved scheme structure and free professional advice were 21.9% ($n = 95$) and 9.2% ($n = 40$), respectively. Planting of trees and/or hedges was significantly associated with climate change motivations concerning the uptake of OGF ($p = 0.048$), with 34.3% ($n = 47$) of farmers who recently planted trees/hedges considering it important, compared with 15.4% ($n = 6$) who did not plant trees/hedges.

## 4.3 Bivariate Associations

### *4.3.1 Pro-environmental diversification behaviours*

Significant statistical associations between pro-environmental behaviours are outlined in Tables 4.6–4.9. Adoption of OGF demonstrated a significant relationship with respondents' age ($p < 0.001$) and farming type ($p < 0.001$) (Table 4.6). A notably higher proportion of respondents who reported farming organically were middle aged or older (i.e. 46 years or older) than non-organic farmer respondents. With respect to farming type, beef farmers accounted for the majority of organic farmers (81.6%, $n = 40$) and under half of non-organic farmers (49.7%, $n = 273$). Adoption of OGF was also significantly related to farm size ($U = 2.968$, $p = 0.003$) and herd size ($U = 6.743$, $p < 0.001$). The mean farm size among organic farmers was 119 acres (48 ha, SD ± 70.5 acres) compared with 180 acres (73 ha, SD ± 128.7 acres) among non-organic

**Table 4.5. Pro-environmental motivators to pursue OGF among Irish farmers ($n = 186$)**

| Variable | Total answers, *n* | Response category | Frequency, *n* (%) |
|---|---|---|---|
| To create a healthier on-farm environment | 183 | Important | 149 (81.4) |
| | | Somewhat important | 23 (12.6) |
| | | Not important | 11 (6.0) |
| To address climate change | 179 | Important | 53 (29.6) |
| | | Somewhat important | 65 (36.3) |
| | | Not important | 61 (34.1) |
| To improve animal welfare | 182 | Important | 63 (34.6) |
| | | Somewhat important | 57 (31.3) |
| | | Not important | 62 (34.1) |
| To get a higher price for organic products | 186 | Important | 104 (55.6) |
| | | Somewhat important | 34 (18.2) |
| | | Not important | 48 (25.7) |

**Table 4.6. Bivariate associations between the adoption of OGF and respondent characteristics**

| | OGF, *n* (%) | | | |
|---|---|---|---|---|
| Variable | Yes | No | $\chi^2$ | *p*-value |
| **Gender** | | | 0.029 | 0.864 |
| Male | 39 (88.6) | 394 (87.8) | | |
| Female | 5 (11.4) | 55 (12.2) | | |
| **Age (years)** | | | 24.840 | <0.001 |
| 18–25 | 1 (2.2) | 43 (9.4) | | |
| 26–35 | 5 (11.1) | 84 (18.4) | | |
| 36–45 | 8 (17.8) | 144 (31.6) | | |
| 46–55 | 13 (28.9) | 113 (24.8) | | |
| 56–65 | 11 (24.4) | 57 (12.5) | | |
| >66 | 7 (15.6) | 15 (3.3) | | |
| **Education** | | | 2.717 | 0.257 |
| Primary/secondary school | 11 (26.2) | 76 (17.1) | | |
| University/vocational degree | 24 (57.1) | 306 (68.8) | | |
| Postgraduate degree/master’s/PhD | 7 (16.7) | 63 (14.2) | | |
| **Farming type** | | | 19.288 | <0.001 |
| Beef | 40 (81.6) | 273 (49.7) | | |
| Dairy | 8 (16.2) | 178 (32.4) | | |
| Beef and dairy | 1 (2.0) | 98 (17.9) | | |
| **Pro-environmental motivations** | | | | |
| *To create a healthier on-farm environment* | | | 5.186 | 0.075 |
| Important | 35 (94.6) | 111 (78.7) | | |
| Somewhat important | 1 (2.7) | 22 (15.6) | | |
| Unimportant | 1 (2.7) | 8 (5.7) | | |
| *To address climate change* | | | 1.719 | 0.423 |
| Important | 10 (27.0) | 43 (30.5) | | |
| Somewhat important | 11 (29.7) | 53 (37.6) | | |
| Unimportant | 16 (43.2) | 45 (31.9) | | |
| *To improve animal welfare* | | | 4.045 | 0.132 |
| Important | 13 (35.1) | 47 (33.3) | | |
| Somewhat important | 16 (43.2) | 41 (29.1) | | |
| Unimportant | 8 (21.6) | 53 (37.6) | | |
| *To get a higher price for organic products* | | | 0.871 | 0.647 |
| Important | 20 (52.6) | 84 (56.8) | | |
| Somewhat important | 6 (15.8) | 28 (18.9) | | |
| Unimportant | 12 (31.6) | 36 (24.3) | | |
| **Barriers to pro-environmental agriculture** | | | 20.335 | <0.001 |
| Lack of well-established “know-how” | 26 (81.3) | 169 (41.6) | | |
| Lower profits | 3 (9.4) | 183 (45.1) | | |
| Increased livestock diseases | 0 (0) | 12 (3.0) | | |
| Reduced fodder production | 3 (9.4) | 42 (10.3) | | |

**Table 4.7. Bivariate associations between agri-environmental scheme participation and respondent characteristics**

| Variable | Scheme involvement, *n* (%) | | $\chi^2$ | *p*-value |
|---|---|---|---|---|
| | Yes | No | | |
| **Gender** | | | 0.001 | 0.978 |
| Male | 221 (88.0) | 212 (88.0) | | |
| Female | 30 (12.0) | 29 (12.0) | | |
| **Age (years)** | | | 16.467 | 0.006 |
| 18–25 | 0 (7.8) | 24 (9.8) | | |
| 26–35 | 38 (14.8) | 50 (20.5) | | |
| 36–45 | 75 (29.3) | 78 (32.0) | | |
| 46–55 | 60 (23.4) | 65 (26.6) | | |
| 56–65 | 47 (18.4) | 21 (8.6) | | |
| > 66 | 16 (6.3) | 6 (2.5) | | |
| **Education** | | | 1.884 | 0.390 |
| Primary/secondary school | 50 (19.9) | 36 (15.3) | | |
| University/vocational degree | 164 (65.3) | 165 (70.2) | | |
| Postgraduate degree/master's/PhD | 37 (14.7) | 34 (14.5) | | |
| **Farming type** | | | 53.171 | < 0.001 |
| Beef | 187 (68.2) | 103 (37.6) | | |
| Dairy | 61 (22.3) | 106 (38.7) | | |
| Beef and dairy | 26 (9.5) | 65 (23.7) | | |
| **Pro-environmental motivations** | | | | |
| *To create a healthier on-farm environment* | | | 2.393 | 0.302 |
| Important | 91 (85.0) | 54 (77.1) | | |
| Somewhat important | 10 (9.3) | 12 (17.1) | | |
| Unimportant | 6 (5.6) | 4 (5.7) | | |
| *To address climate change* | | | 3.082 | 0.214 |
| Important | 32 (29.9) | 19 (27.1) | | |
| Somewhat important | 34 (31.8) | 31 (44.3) | | |
| Unimportant | 41 (38.3) | 20 (28.6) | | |
| *To improve animal welfare* | | | 4.633 | 0.099 |
| Important | 33 (30.8) | 27 (38.6) | | |
| Somewhat important | 41 (38.3) | 16 (22.9) | | |
| Unimportant | 33 (30.8) | 27 (38.6) | | |
| *To get a higher price for organic products* | | | 0.597 | 0.742 |
| Important | 62 (55.9) | 41 (55.4) | | |
| Somewhat important | 22 (19.8) | 12 (16.2) | | |
| Unimportant | 27 (24.3) | 21 (28.4) | | |
| **Barriers to pro-environmental agriculture** | | | 1.889 | 0.596 |
| Lack of well-established "know-how" | 104 (47.5) | 90 (41.7) | | |
| Lower profits | 87 (39.7) | 97 (44.9) | | |
| Increased livestock diseases | 5 (2.3) | 7 (3.2) | | |
| Reduced fodder production | 23 (10.5) | 22 (10.2) | | |

**Table 4.8. Bivariate associations between adoption of land management measures and respondent characteristics**

| Variable | Adoption of measures, *n* (%) | | $\chi^2$ | *p*-value |
|---|---|---|---|---|
| | Yes | No | | |
| **Gender** | | | 4.421 | 0.036 |
| Male | 359 (86.5) | 75 (94.9) | | |
| Female | 56 (13.5) | 4 (5.1) | | |
| **Age (years)** | | | 7.589 | 0.180 |
| 18–25 | 33 (7.8) | 11 (13.8) | | |
| 26–35 | 72 (17.1) | 16 (20.0) | | |
| 36–45 | 127 (30.2) | 25 (31.3) | | |
| 46–55 | 109 (25.9) | 18 (22.5) | | |
| 56–65 | 58 (13.8) | 10 (12.5) | | |
| > 66 | 22 (5.2) | 0 (0) | | |
| **Education** | | | 1.105 | 0.575 |
| Primary/secondary school | 76 (18.6) | 11 (14.1) | | |
| University/vocational degree | 276 (67.5) | 54 (69.2) | | |
| Postgraduate degree/master's/PhD | 57 (13.9) | 13 (16.7) | | |
| **Farming type** | | | 0.224 | 0.894 |
| Beef | 224 (52.6) | 45 (54.2) | | |
| Dairy | 129 (30.3) | 23 (27.7) | | |
| Beef and dairy | 73 (17.1) | 15 (18.1) | | |
| **Pro-environmental motivations** | | | | |
| *To create a healthier on-farm environment* | | | 2.671 | 0.263 |
| Important | 129 (82.2) | 14 (77.8) | | |
| Somewhat important | 18 (11.5) | 4 (22.2) | | |
| Unimportant | 10 (6.4) | 0 (0) | | |
| *To address climate change* | | | 8.465 | 0.015 |
| Important | 51 (32.5) | 1 (5.6) | | |
| Somewhat important | 58 (36.9) | 6 (33.3) | | |
| Unimportant | 48 (30.6) | 11 (61.1) | | |
| *To improve animal welfare* | | | 0.325 | 0.850 |
| Important | 51 (32.5) | 7 (38.9) | | |
| Somewhat important | 51 (32.5) | 5 (27.8) | | |
| Unimportant | 55 (35.0) | 6 (33.3) | | |
| *To get a higher price for organic products* | | | 5.446 | 0.066 |
| Important | 83 (51.9) | 17 (77.3) | | |
| Somewhat important | 31 (19.4) | 3 (13.6) | | |
| Unimportant | 46 (28.7) | 2 (9.1) | | |
| **Barriers to pro-environmental agriculture** | | | 3.339 | 0.342 |
| Lack of well-established "know-how" | 168 (46.4) | 25 (35.7) | | |
| Lower profits | 148 (40.9) | 35 (50.0) | | |
| Increased livestock diseases | 9 (2.5) | 3 (4.3) | | |
| Reduced fodder production | 37 (10.2) | 7 (10.0) | | |

**Table 4.9. Bivariate associations between use of low-emission fertilisers and respondent characteristics**

| | Use of low-emission fertilisers, *n* (%) | | | |
|---|---|---|---|---|
| **Variable** | **Yes** | **No** | $\chi^2$ | ***p*-value** |
| **Gender** | | | 8.169 | 0.004 |
| Male | 292 (91.0) | 143 (82.2) | | |
| Female | 29 (9.0) | 31 (17.8) | | |
| **Age (years)** | | | 9.934 | 0.077 |
| 18–25 | 35 (10.7) | 8 (4.6) | | |
| 26–35 | 64 (19.6) | 25 (14.3) | | |
| 36–45 | 94 (28.7) | 60 (34.3) | | |
| 46–55 | 79 (24.2) | 48 (27.4) | | |
| 56–65 | 44 (13.5) | 24 (13.7) | | |
| >66 | 11 (3.4) | 10 (5.7) | | |
| **Education** | | | 15.021 | <0.001 |
| Primary/secondary school | 41 (12.9) | 45 (26.6) | | |
| University/vocational degree | 231 (72.4) | 99 (58.6) | | |
| Postgraduate degree/master's/PhD | 47 (14.7) | 25 (14.8) | | |
| **Farming type** | | | 91.401 | <0.001 |
| Beef | 126 (38.3) | 144 (81.8) | | |
| Dairy | 135 (41.0) | 13 (7.4) | | |
| Beef and dairy | 68 (20.7) | 19 (10.8) | | |
| **Pro-environmental motivations** | | | | |
| *To create a healthier on-farm environment* | | | 3.901 | 0.142 |
| Important | 76 (76.8) | 68 (88.3) | | |
| Somewhat important | 16 (16.2) | 6 (7.8) | | |
| Unimportant | 7 (7.1) | 3 (3.9) | | |
| *To address climate change* | | | 0.163 | 0.922 |
| Important | 30 (30.3) | 23 (29.9) | | |
| Somewhat important | 37 (37.4) | 27 (35.1) | | |
| Unimportant | 32 (32.3) | 27 (35.1) | | |
| *To improve animal welfare* | | | 3.526 | 0.172 |
| Important | 29 (29.3) | 30 (39.0) | | |
| Somewhat important | 30 (30.3) | 26 (33.8) | | |
| Unimportant | 40 (40.4) | 21 (27.3) | | |
| *To get a higher price for organic products* | | | 4.367 | 0.113 |
| Important | 63 (61.8) | 38 (46.3) | | |
| Somewhat important | 16 (15.7) | 18 (22.0) | | |
| Unimportant | 23 (22.5) | 26 (31.7) | | |
| **Barriers to pro-environmental agriculture** | | | 6.644 | 0.084 |
| Lack of well-established "know-how" | 117 (41.6) | 73 (50.7) | | |
| Lower profits | 130 (46.3) | 49 (34.0) | | |
| Increased livestock diseases | 6 (2.1) | 6 (4.2) | | |
| Reduced fodder production | 28 (10.0) | 16 (11.1) | | |

farmers; the mean herd size among organic farmers was 51 cattle (SD ± 61.1), while mean herd size among non-organic farmers was 144 cattle (SD ± 108.9). A further significant relationship was identified between the belief scores of organic and conventional farmers ($U = -3.831$, $p < 0.001$), with respondents farming organically demonstrating higher favourability to pro-environmental agriculture (71.3%, SD ± 6.2) than those farming conventionally (66.1%, SD ± 8.4).

A notable relationship was identified between the adoption of OGF and identified barriers to pro-environmental agriculture ($\chi^2 = 20.335$, $p < 0.001$). Most farmers currently farming organically (81.3%, $n = 26$) identified a lack of well-established "know-how" as a barrier, compared with 41.6% ($n = 169$) of non-organic farmers.

Similarly to the adoption of OGF, participation in agri-environmental schemes was also significantly related to respondents' age ($p = 0.006$) and farming type ($p < 0.001$) (Table 4.7). Differences in agri-environmental scheme involvement were most visible among middle-aged and older farmers (i.e. 56 or older) and those who reported beef farming. Involvement in agri-environmental schemes was also related to farm size ($p = 0.017$) and herd size ($p < 0.001$). The mean farm size for farmers participating in agri-environmental schemes was 170 acres (69 ha, SD ± 117.4 acres) compared with 180 acres (73 ha, SD ± 115.0 acres) for non-participants. The mean herd size for farmers participating in agri-environmental schemes was 111 cattle (SD ± 98.4) compared with 158 cattle (SD ± 110.0) for non-participants.

Adoption of pro-environmental land management measures exhibited a significant relationship with gender ($p = 0.036$); 93.3% ($n = 56$) of female farmers reported adoption of at least one relevant measure, compared with 82.7% ($n = 359$) of male farmers. Adoption of land management measures was also associated with respondents' belief score ($p = 0.002$) and climate change motivations related to OGF ($p = 0.015$). Respondents who undertook land management measures attained higher mean belief scores (67.1%, SD ± 7.7%) than those who did not (63.0%, SD ± 10.3%). Almost one-third of respondents (32.5%, $n = 51$) undertaking land management measures regarded climate change mitigation as an important motivation, compared with just 5.6% ($n = 1$) of farmers who did not undertake such measures.

The use of low-emission fertilisers was significantly associated with gender ($p = 0.004$), education ($p < 0.001$) and farm type ($p < 0.001$) (Table 4.9). A higher proportion of respondents reporting the use of low-emission fertilisers were males (91.0%, $n = 292$) and reported a third-level education, i.e. university/vocational degree or higher (87.1%, $n = 278$). Most farmers reporting non-use of low-emission fertilisers were beef farmers (81.8%, $n = 144$). The use of low-emission fertilisers was also significantly related to farm size ($p < 0.001$) and herd size ($p < 0.001$), due to the difference mentioned above in farm type (i.e. dairy vs beef). This might also be because a higher proportion of dairy than beef farmers are in derogations and would be required to use low-emission slurry-spreading technologies. Use of low-emission fertilisers was also related to overall beliefs regarding pro-environmental agriculture ($p = 0.021$); farmers who did not use low-emission fertilisers scored higher (67.2, SD ± 9.1) than those who did (66.1, SD ± 7.9).

### 4.3.2 *Pro-environmental diversification beliefs*

Unexpectedly, calculated pro-environmental diversification belief scores did not exhibit any statistically significant relationship with socio-demographic or motivation-based variables. However, pro-environmental beliefs scores were significantly associated with the adoption of OGF ($p < 0.001$), employment of pro-environmental land management measures ($p = 0.002$) and use of low-emission fertilisers ($p = 0.021$) (Figure A1.1). Respondents who currently farmed organically attained a mean belief score of 71.3% (SD ± 6.2%), while those who did not attained a mean belief score of 66.1% (SD ± 8.4%). Respondents who undertook pro-environmental land management actions also attained a higher mean score (67.1%, SD ± 7.7%) than their counterparts (63.0%, SD ± 10.3%). Respondents who did not use low-emission fertilisers exhibited a higher mean score (67.4%, SD ± 9.0%) than those who used low-emission fertilisers (66.1%, SD ± 8.0%). Herd size represented the sole farm characteristic significantly associated with belief scores ($p = 0.012$), with herd size negatively correlated with belief scores. Pro-environmental belief scores were also related to prioritised barriers to pro-environmental behaviours ($p < 0.001$), with

**Table 4.10. Model for adoption of organic agriculture**

| Variable | β | SE | Wald | *p*-value | OR | 95% CI for OR |
|---|---|---|---|---|---|---|
| Age | −0.500 | 0.179 | 12.817 | 0.025 | 0.607 | 0.427 to 0.862 |
| Herd size | 0.013 | 0.004 | 10.999 | 0.001 | 1.013 | 1.005 to 1.021 |
| Pro-environmental beliefs | −0.059 | 0.015 | 16.304 | < 0.001 | 0.943 | 0.916 to 0.970 |

**CI, confidence interval; SE, standard error.**

**Table 4.11. Model for participation in agri-environmental schemes**

| Variable | β | SE | Wald | *p*-value | OR | 95% CI for OR |
|---|---|---|---|---|---|---|
| Age (56–65 years) | 0.790 | 0.443 | 3.180 | 0.075 | 2.203 | 0.925 to 5.247 |
| Farming type (dairy) | −1.404 | 0.254 | 30.43 | < 0.001 | 0.246 | 0.149 to 0.404 |
| Farming type (beef and dairy) | −1.666 | 0.311 | 28.777 | < 0.001 | 0.189 | 0.103 to 0.347 |
| Farm size | 0.03 | 0.001 | 9.145 | 0.002 | 1.003 | 1.001 to 1.005 |

**CI, confidence interval; SE, standard error.**

respondents who identified a lack of well-established “know-how” scoring markedly higher than other respondents.

## 4.4 Multivariate Modelling

### *4.4.1 Adoption of organic agriculture*

In the optimal model for adoption of organic agriculture (Table 4.10), respondent age, herd size and pro-environmental belief scores significantly predicted current adoption of organic agriculture. Younger respondents were less likely to adopt organic agriculture (odds ratio (OR) = 0.607), with those with lower pro-environmental belief scores also significantly less likely to adopt organic agriculture (OR = 9.43). Decreasing herd size was positively associated with being an organic farmer (OR = 1.013).

### *4.4.2 Agri-environmental scheme participation*

In the optimal model for participation in agri-environmental schemes, respondent age ($p = 0.038$), farming type ($p < 0.001$) and farm size ($p = 0.002$) were the significant explanatory variables. A rise in the respondent age category generally led to increased scheme participation, with respondents aged 56–65 years and > 66 years more than twice as likely to engage in schemes as their younger counterparts. Dairy farmers (OR = 0.246) and beef farmers (OR = 0.189) were significantly less likely to participate in agri-environmental schemes than those farming both beef and dairy. In contrast to the negative association with agri-scheme involvement, farm size was positively associated with agri-environmental scheme participation (OR = 1.003, $p = 0.002$) (Table 4.11).

# 5 A Life Cycle Assessment of Diversification Options for Grass-based Cattle Farming Systems

Diversification is generally thought to affect the environmental performance of cattle farming positively. Several options previously discussed support this assertion, but few have been examined at a systems level for grass-based livestock farms. Measuring the environmental footprint of diversification options at this scale is complex, time-consuming and costly. A practical alternative to direct measurement of environmental impacts is mathematical modelling. Generally, models of production systems rely on experimental research and farm input and output data to simulate these impacts. Many modelling methods have been developed to model the footprint of production systems. The principal approach applied to model the impacts of farms is LCA (van der Werf *et al*., 2020), which is the recognised international method for C labelling. The general stages and principles of LCA are defined by the International Organization for Standardization (ISO, 2006a,b). The majority of LCA models of farms adhere to this standard. They are often applied to evaluate farm systems and practices or new technologies. However, most LCA studies have focused on indoor systems (Chobtang *et al.*, 2016), and many are restricted to a single impact category. The environmental impacts of grass-based cattle farms in temperate regions have been assessed with this approach (e.g. Payen *et al.*, 2020). However, few of these studies have considered diversification practices.

LCA was employed in this study to model common cattle farming systems, i.e. suckler calf to beef and spring-calving dairy systems. Both of these bovine systems were evaluated over 3 years (2017–2019) and are nationally representative. The principal objective of this LCA study was to assess the influence of diversification options on the resource use and potential environmental impacts of conventional grass-based cattle farms. Three diversification options frequently recommended for livestock farms were examined: (1) mixed grass–legume swards, (2) OGF and (3) silvopasture AFS. Detailed results of this analysis are presented in O'Brien *et al*. (2023).

## 5.1 Materials and Methods

### *5.1.1 Cattle farms*

The characteristics of an average Irish suckler calf to beef production system and a typical spring-calving dairy system (Table 5.1) were determined using mainly national statistics. The Teagasc National Farm Survey (NFS) was the primary dataset employed to define the agricultural parameters of cattle farms. The purpose of the NFS is to monitor the viability of Irish agriculture and supply reliable information to the Farm Accountancy Data Network of the European Union (Dillon *et al.*, 2022). The survey is conducted every year on 900–1100 farms spread throughout the country. The farm population governs the number of farms included in the survey. A random sampling methodology is applied to select farms. Farms in the survey are weighted according to land area using aggregation factors from the Central Statistics Office (CSO, 2021), to ensure that the NFS is representative of the farm population. For dairy farms, the NFS collects data from between 250 and 300 farms and represents 16,000 suppliers. With regard to beef farms, the NFS gathers information from between 350 and 400 beef farms, with suckling being the dominant enterprise, accounting for an estimated 31,500 farms.

Almost all of the cattle farms in the NFS sample operate grass-based production systems. Grass that is properly managed is an inexpensive and nutritious feed capable of supporting good levels of milk and beef production. Ireland's cool, moist climate and organic matter-rich soils create conducive conditions for grass production. Most cattle farmers try to exploit these conditions by aligning turnout with the onset of the growing season. Animals are let out to pasture once ground conditions are suitable for grazing and as soon as supply is sufficient (O'Brien *et al.*, 2023). The majority of beef and dairy cows are turned out to grass immediately after calving. For the dairy system, the mean date for calving was 4 March, and for the suckler calf to beef farm system this was 2 April (Table 5.1).

**Table 5.1. General characteristics of national average grass-based cattle farming systems in Ireland, 2017–2019**

| Characteristic | Unit | Farm system[a] | |
|---|---|---|---|
| | | Dairy | Suckler calf to beef |
| **Farm** | | | |
| Grassland | ha | 40 | 34 |
| Soil K status | % ≥index 3[b] | 46 | 39 |
| Soil P status | % ≥index 3 | 51 | 48 |
| Optimal pH | % soils | 49 | 37 |
| Land type | % moderate/good | 56 | 42 |
| Fertiliser N | kg N/ha | 185 | 83 |
| Fertiliser P | kg P/ha | 12 | 10 |
| Fuel consumption | l/ha | 80.9 | 51.9 |
| Grass utilisation | kg DM/ha | 8.1 | 6.2 |
| **Herd** | | | |
| Cows | Average hd | 67.3 | 23.9 |
| 0–1 year old | Average hd | 19.9 | 21.8 |
| 1–2 years old | Average hd | 15.2 | 22.7 |
| 2+ years old | Average hd | – | 11.6 |
| Replacement rate | % cows | 21 | 18 |
| Age at first calving | Month | 24 | 30 |
| Mean calving date | Date | 4 March | 2 April |
| Grazing season – cows | Day | 236 | 219 |
| Concentrate feedstuffs | kg/LU | 1025 | 299 |
| Stocking rate | LU/ha | 2.1 | 1.6 |
| **Production** | | | |
| Heifer slaughter age | Month | – | 25 |
| Heifer carcass weight | kg | – | 333 |
| Steer slaughter age | Month | – | 28 |
| Steer carcass weight | kg | – | 395 |
| Beef carcass output | kg/ha | 113 | 241 |
| Milk produced | kg/cow | 5750 | – |
| Milk fat and protein | kg/cow | 439 | – |

**[a]Teagasc 2027 sectoral roadmaps for dairy and beef production (Teagasc, 2020).**

**[b]Soils at nutrient index 3 or 4 have good fertility levels.**

**DM, dry matter; hd, head; K, potassium; LU, livestock unit.**



On dairy farms, cows normally graze sections of a field or paddocks in rotation. A paddock is usually grazed until a desired post-grazing height (e.g. 4 cm) has been reached. The herd usually spends 24–36 hours in a paddock. The rotation length ranges from 21 to 26 days between April and mid-August. During this period, synthetic fertiliser N is spread after a paddock is grazed or blanket spread across the grazing area on a monthly basis. The amount of synthetic fertiliser N applied on dairy farms averaged 185 kg N/ha between 2017 and 2019 (Table 5.1) (O'Brien *et al.*, 2023).

On average, the suckler calf to beef farms spread 83 kg of synthetic fertiliser N per hectare (Table 5.1). Continuous grazing is an alternative method of grassland management used on some beef farms. In this grazing system, animals graze a field for several days or weeks before moving to a new field. The period beef animals spend in a field is usually set arbitrarily. The quality of pasture in this type of grazing system is often moderate, and yields are usually low (5–7 t dry matter (DM)/ha). Supplementary feedstuffs and roughage are offered to cattle during prolonged periods of poor grass growth. Concentrate feeds are also offered to cattle as part of finishing diets (O'Mara, 2007). When grass growth exceeds demand on cattle farms in summer and early autumn, it is harvested and conserved in pits and/or made into silage or bales. These conserved forages are offered to the herd during the housing period.

Cattle are re-housed when ground conditions become unsuitable for grazing in late autumn or winter (i.e. October–December). Most cows and heifers are housed in sheds with cubicles (free-stalls) and slatted or solid floors. Beef heifers, steers and bulls are principally kept in open houses with slatted floors. Housing for calves normally contains solid floors and bedding material (e.g. straw). Dung and urine excreted on bedding (i.e. solid manure) is collected periodically and kept in a dungstead or farmyard manure store(s). Manure with little or no waste bedding (i.e. liquid manure or slurry) is stored in reinforced concrete tanks underneath animal houses or stored above or below ground in uncovered or covered tanks. Cattle slurry and solid manure are spread onto grassland during the growing season (O'Brien *et al*, 2023).

### *5.1.2 Life cycle assessment*

The environmental performance of grass-based cattle farms was quantified using a pair of hybrid bio-economic LCA models developed by Teagasc in conjunction with university partners (Herron *et al*., 2021a,b). The Teagasc beef and dairy LCA models were applied in accordance with the ISO (2006a) framework, which is broadly divided into four stages: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation. The LCA model was adapted to determine the main potential impacts of cattle farming, namely global warming potential (GWP), acidification, marine and freshwater eutrophication, non-renewable energy (NRE) depletion and land occupation. These environmental impact categories were selected after reviewing national regulations and global LCA studies. Other important impacts identified in this review, i.e. biodiversity and ecotoxicity, were omitted because of the absence of a standard metric for biodiversity and a lack of data on the fate of agrochemicals and heavy metals in the local environment (O'Brien *et al*., 2023).

The boundaries of the LCA models extend from the extraction and acquisition of raw material through to the export of milk and cattle to creameries and beef factories. Hence, both models were delimited to include on-farm impacts from daily farming activities and pre-farm impacts embodied in inputs, e.g. electricity. Agricultural inputs reported to have negligible impact, e.g. medicines (Saunders and Barber, 2007), were excluded from the analysis. These inputs and agricultural outputs were recorded in the inventory analysis stage. Where possible, the NFS collected foreground data on resource use from cattle farms. National databases and reports were used to fill gaps in foreground data for vegetation and animals, e.g. birth weights. Secondary data from Nemecek and Kägi (2007) were coupled with foreground data on field operations to quantify the materials, e.g. fossil fuels consumed by agricultural contractors. Emissions from materials and substances used on-farm were quantified using the factors and algorithms reported in Table 5.2 (O'Brien *et al*., 2023).

The emission factors for calculating carbon dioxide ($CO_2$), $CH_4$, nitrous oxide ($N_2O$), nitrogen oxides ($NO_x$), ammonia ($NH_3$), $NO_3^-$, P, phosphate ($PO_4^{3-}$) and sulphur dioxide ($SO_2$) emissions within the cattle LCA models have previously been reported in detail by Herron *et al*. (2021a,b). Briefly, GHG and $NH_3$ emissions from on-farm sources were computed in accordance with Intergovernmental Panel on Climate Change (IPCC, 2019) guidelines and national emissions inventories (EPA, 2020a,b). Short-term sources of $CO_2$ were considered neutral with respect to global warming because the IPCC (2019) guidelines report that $CO_2$ respired by autotrophs and heterotrophs is rapidly reabsorbed by plants during photosynthesis. C loss and sequestration for a change in land use were assumed to reach a steady state after 20 years of constant land use (IPCC, 2019). However, permanent grassland soils in temperate climate zones are known to sequester C for significantly longer than 20 years (O'Brien *et al*., 2023). This land use was treated as a long-term sink for C and estimated to sequester 0.5 t C/ha per year (Byrne *et al*., 2018).

$CH_4$ from enteric fermentation, a ruminant digestive process, was estimated as a function of gross energy intake. The percentage of gross energy intake emitted

**Table 5.2. Inventory analysis of on-farm sources of emissions in grass-based cattle farming systems**

| Emission source | $CO_2$[a] (kg/kg) | $CH_4$[b,c] (kg/hd) | $N_2O$-N[a,c] (% of N) | $NH_3$-N[d] (% of N) | $NO_x$-N[e] (kg/kg N) | $NO_3$-N[a] (% of N) | P[e] (kg/ha) | $SO_2$[e] (g/kg) |
|---|---|---|---|---|---|---|---|---|
| **Livestock** | | | | | | | | |
| Enteric fermentation | | | | | | | | |
| Housing: conserved forage | | $(DEI^a \times (0.096 + 0.035 \times F_{prp}{}^c) - (2.298 \times FL^d - 1))/55.65$ | | | | | | |
| Feedlot: concentrate > 85% diet | | $(0.04 \times GEI^e)/55.65$ | | | | | | |
| Grazing | | $(0.063 \times GEI)/55.65$ | | | | | | |
| **Housing and manure storage** | | | | | | | | |
| Slurry tank with crust/cover | | Manure VS × $B_o$ × 0.67 × MCF[f] | 0.5 | 3 | 0.002 | | | |
| Slurry tank without crust/cover | | Manure VS × $B_o$ × 0.67 × MCF | 0 | 6 | 0 | | | |
| Slurry tank under slatted unit | | Manure VS × $B_o$ × 0.67 × MCF | 0.2 | 3 | 0.001 | | | |
| Dungstead: solid manure (> 20% DM) | | Manure VS × $B_o$ × 0.67 × MCF | 1 | 21 | 0.004 | 1.2 | | |
| Housing on slatted floor | | | | 17 | | | | |
| Housing on straw bedding | | | | 2–10 | | | | |
| **Feed production** | | | | | | | | |
| Diesel use | 3.14 | | | | 0.030[g] | | | 2.57 |
| Gasoline use | 3.13 | | | | 0.020[g] | | | 0.07 |
| CAN spreading | | | 1.49 | 0.8 | 0.005 | 10 | | |
| Urea spreading | 2.68 | | 0.25 | 15.5 | 0.001 | 10 | | |
| Protected urea spreading | 2.68 | | 0.4 | 0.8 | 0.001 | 10 | | |
| Lime application | 1.61 | | | | | | | |
| Crop residues | | | 1.0 | | 0.004 | | | |
| Slurry application | | | 1.0 | 16–29 | 0.004 | 10 | | |
| Solid manure application | | | 1.0 | 41 | 0.004 | 10 | | |
| **Manure excreted on pasture** | | | | | | | | |
| Dung | | | 0.3 | 4 | 0.001 | 10 | | |
| Urine | | | 1.2 | 4 | 0.004 | 10 | | |
| Nutrient leaching | | | 1.1[f] | | | | [h]$0.06 \times F_{gw}$ | |
| Nutrient run-off | | | 1.0[f] | | | | [i]$0.25 \times F_{ro}$ | |

**[a]EPA (2020a).**
**[b]Yan *et al.* (2009).**
**[c]IPCC (2019).**
**[d]Duffy *et al.* (2020).**
**[e]Nemecek and Kagi (2007).**
**[f]Percentage of $NO_3^-$/N loss.**
**[g]Per kilogram of fuel.**
**[h]$F_{gw} = (1 + 0.2/80 \times \text{slurry } P_2O_5)$.**
**[i]$F_{ro} = (1 + 0.0025 \times \text{fertiliser } P_2O_5 + 0.7/80 \times \text{slurry } P_2O_5 + 0.005 \times \text{solid manure } P_2O_5)$.**
**CAN, calcium ammonium nitrate; DEI, digestible energy intake; GEI, gross energy intake; hd, head; MCF, methane conversion factor; VS, volatile solids.**

as $CH_4$ on pasture fell from 6.5% to 6.3% (IPCC, 2019). For cattle that were indoors and on a grass silage-based diet, the diet-specific conversion factor remained the same, but increased from 3% to 4% for cattle on an ad-lib concentrate diet. A new tier 2 model from the IPCC (2019) guidelines was applied to estimate $CH_4$ emissions from stored manure. Country-specific emission factors from Teagasc (Harty *et al.*, 2016; Krol *et al.*, 2016) were adopted for $N_2O$ losses associated with organic manure and synthetic fertilisers. $NH_3$ and $NO_x$ emissions from manure were quantified using the mass flow approach described in the Irish informative inventory report (EPA, 2020b). The same report was used to estimate emissions from synthetic fertilisers (O'Brien *et al.*, 2023).

$NO_3^-$ leaching from N inputs was fixed at 10% of N (EPA, 2020a). P loss was quantified based on the P surplus and the amount of P applied. P surplus was calculated by way of a farm-gate balance. Imports and exports of P were calculated on an annual basis and the difference was used to quantify the P surplus at a farm level. The potential loss of surplus P from index 2 and 3 soils was calculated using the equations in Table 5.2, from Nemecek and Kägi (2007). Where possible, pre-farm emissions and resources embodied in purchased inputs were calculated with data from national reports. For example, GHG emissions from power generation were estimated using data from the national inventory and energy reports (SEAI, 2020). The materials and environmental losses associated with inputs produced overseas were estimated using international studies and LCA databases such as Ecoinvent (2015). These emissions and resources were added to the on-farm inventory results and translated into environmental impacts in the impact assessment stage (O'Brien *et al.*, 2023).

The GWP, also referred to as the C footprint of cattle systems, was determined using $CO_2$ conversion factors from the IPCC (2013) – $CO_2$: 1; $CH_4$: 28–30; $N_2O$: 265. The accumulated exceedance method recommended by the European Commission (2018) was applied to determine acidification potential (ACP) in moles of hydrogen ion ($H^+$)-equivalent (eq) using factors from Posch *et al.* (2008) – $SO_2$: 1.1; $NH_3$: 1.2; $NO_x$: 0.6. Marine eutrophication potential (MEP) was quantified in kg N-eq using factors reported by Huijbregts *et al.* (2017) – $NH_3$: 0.082; $NO_x$: 0.03; $NO_3^-$: 0.023. Freshwater eutrophication potential (FEP) was computed with factors from the same source, but in kg P-eq – P: 0.7; $PO_4$: 0.23. NRE depletion was determined in megajoules (MJ) using lower heating values from the cumulative energy demand method (Guinee *et al.*, 2002) – crude oil: 42.6 MJ/kg; natural gas: 35 MJ/m$^3$; coal: 18 MJ/kg. Land occupation was quantified by aggregating the area of land a farm used for housing and feed production with the areas required for purchased farm inputs, e.g. feedstuffs.

As explained in O'Brien *et al.* (2023), impact categories were scaled relative to the functions of beef and dairy systems. Land use was chosen as a common function for both systems. Beef carcass weight (CW) was the primary functional unit for beef farms, and fat- and protein-corrected milk (FPCM) was the main unit for dairy. FPCM was standardised to 4% fat and 3.3% true protein. In addition to milk, dairy cows produce meat at the end of their life cycle and produce calves for the beef herd. A portion of the environmental impact of a dairy farm was allocated to CW. Economic criteria were used to distribute an environmental impact between co-products. This method divides an impact category between co-products based on their share of a dairy farm's annual revenue. Economics was also used to allocate an environmental impact between agricultural inputs, e.g. rolled barley grains and straw. The quantity of concentrate feed offered to cattle was recorded throughout the year and fed into the LCA models through the NFS database. Both LCA models operated on a monthly basis and reported environmental impacts on an annualised basis.

### 5.1.3 Diversification scenarios

As reported by O'Brien *et al.* (2023), the diversification scenarios evaluated for both farm types were GWC swards, OGF and AFS. For the GWC swards scenario, ryegrass pastures were converted to GWC swards, where beef and dairy farms were predominantly located on moderately or well-drained soils. This conversion was carried out in accordance with the steps in Hennessy *et al.*'s (2021) management guide for white clover. Briefly, 10–15% of the farm was reseeded annually. Grassland was cultivated when soil temperature exceeded 7°C in spring. Before cultivation, glyphosate was applied at a rate of 5 l/ha to control weeds. Grass varieties were subsequently sown at a rate of 30 kg/ha and contained 5 kg/ha of white clover. At or shortly before sowing, 40 kg of P and 90 kg of K fertiliser were applied per hectare to aid the establishment. In summer, synthetic fertiliser N was reduced to increase the share of white clover in mixed swards. The white clover content of the sward in summer and autumn ranged from 30% to 40%. The amount of N fixed was estimated based on the content of white clover in the sward and the fertiliser N rate (Enriquez-Hidalgo *et al*., 2016; Hennessy *et al*., 2021). White clover was also oversown (5 kg/ha) on about one-fifth of the farm annually. Pastures were reseeded after 8–10 years when white clover became unproductive.

Clover and organic manure were the sole N inputs in the OGF scenario. Two species of clover were grown on organic beef and dairy farms: *Trifolium repens* (white) and *Trifolium pratense* (red). The former was established using the same procedure as described for the GWC swards scenario but without glyphosate. White clover was primarily managed for grazing. Red clover was generally conserved as silage. Planting of red clover was carried out in April following field preparation and in accordance with Teagasc guidelines (Conaghan and Clavin, 2017). It was sown with companion hybrid ryegrasses in a 50:50 mixture. The sowing rate for the mixture was 30 kg/ha. Red clover was allowed to flower before the initial silage harvest. Two or three cuts of red clover silage were taken each year. Solid manure and rock $PO_4^{3-}$ were applied on the crop at a combined rate of 14–20 kg P/ha. The crop also received 35 kg P/ha in the establishment phase. Silage was mowed 7–8 cm above ground levels. The crop was estimated to have a lifespan of 4–5 years. Red clover fields were rotated every 5 years to reduce the build-up of pests and diseases (O'Brien *et al*., 2023).

Switching from a conventional to an organic sward did not affect turnout and housing dates. However, slatted floors in cattle houses were partly changed to solid floors with straw bedding. In addition, the housing area was increased to comply with OGF rules (Teagasc, 2017). The mean calving date did not differ for the organic dairy system, but the milking frequency was reduced to once a day. This change was estimated to decrease milk volume by 36%. It was also assumed to increase the fat content of milk to 4.5% and increase the protein content to 3.7% (Teagasc, 2022). Concentrate supplementation was decreased to 140 kg DM/dairy cow and restricted to organic ingredients. For beef cows, calving patterns, calving rates and age at first calving and slaughter were unaffected by the switch to organics, but slaughter weights for steers were reduced to an average of 373 kg CW/head for commercial enterprises (Teagasc, 2017). Organic concentrate supplements were offered to cattle at a similar rate as conventional feeds in the reference beef system (O'Brien *et al*., 2023).

As described in O'Brien *et al*. (2023), for the AFS scenario, 10% of the reference dairy farm and 20% of the conventional suckler calf to beef system were converted to silvopasture. Sycamore trees were planted 2 m apart in 8 × 8 m blocks. Twenty-five blocks were established per hectare, which equated to 400 sycamore trees. Shelters were erected around blocks to protect saplings. The pasture was cut for silage in the establishment phase, and cattle under 6 months of age grazed between the blocks. After 7 years, cattle aged under 24 months were allowed to graze in silvopasture. Shelters were removed as the plants matured. Shading was assumed to reduce grass yield by 25% after 10 years of AFS (DAERA, 2016). To compensate for the shortage of fodder in the silvopasture, fertiliser N was increased by 8–12 kg N/ha on permanent pasture. Thinning was undertaken to manage grass growth and development of sycamore trees, and C sequestration was modelled with the Forest Carbon Tool (Teagasc, 2021). Silvopasture was assumed to reduce soil moisture content and improve infiltration based on the results of a long-term study in Northern Ireland (McAdam *et al*., 2018). This facilitated a 4- to 6-week extension to the grazing season for heifers below 2 years of age in the dairy system and a 4- to 8-week increase for growing cattle in the beef system.

## 5.2 Results and Discussion

### 5.2.1 *Conventional farming*

Baseline environmental impacts for national average cattle farming systems are presented in Table 5.3. The average dairy farm had a total GWP, i.e. C footprint, of 0.82 t $CO_2$-eq/t FPCM and the suckler calf to beef farms had a total GWP of 19.5 t $CO_2$-eq/t CW. Excluding C sequestration increased the total GWP of the average dairy system to 0.98 kg $CO_2$-eq/kg FPCM. The total GWP of the average suckler calf to beef system was 40% greater without C sequestration. On-farm GHG sources accounted for 82% of the total GWP of dairy

**Table 5.3. On-farm and cradle to farm-gate (total) environmental impacts, at midpoint level, for national average grass-based cattle farming systems in Ireland, 2017–2019**

| | | | Dairy | | Suckler calf to beef | |
|---|---|---|---|---|---|---|
| **Impact category** | **Unit** | **Location** | **Per t of FPCM** | **Per ha** | **Per t of CW** | **Per ha** |
| GWP | t $CO_2$-eq | On-farm | 0.67 | 7.7 | 17.5 | 4.2 |
| | | Total | 0.82 | 9.4 | 19.5 | 4.7 |
| Acidification | mol $H^+$-eq | On-farm | 5.0 | 56.9 | 140.6 | 33.9 |
| | | Total | 6.1 | 69.5 | 157.2 | 37.9 |
| Freshwater eutrophication | g P-eq | On-farm | 24.9 | 285.0 | 1087 | 261.8 |
| | | Total | 42.3 | 484.7 | 1404 | 338.2 |
| Marine eutrophication | kg N-eq | On-farm | 3.8 | 43.0 | 104.1 | 25.1 |
| | | Total | 4.5 | 52.0 | 111.4 | 26.8 |
| NRE depletion | GJ | On-farm | 0.3 | 3.2 | 7.9 | 1.9 |
| | | Total | 2.6 | 29.2 | 46.4 | 11.2 |
| Land occupation | $m^2$ | On-farm | 874 | | 41,527 | |
| | | Total | 987 | | 42,718 | |

**CW, beef carcass weight; eq, equivalent; FPCM, fat- and protein-corrected milk.**



production and 90% of the total GWP of suckler calf to beef production (O'Brien *et al.*, 2023).

Consistent with Asem-Hiablie *et al.* (2019) and Ledgard *et al.* (2020), $CH_4$ was the most prevalent GHG, making up 62% of total GWP in the dairy system and 73% in the beef system. Enteric fermentation of feed was the principal driver of $CH_4$ emissions (Figures 5.1 and 5.2). $N_2O$ was the second most emitted GHG in terms of GWP, followed by $CO_2$. The former accounted for 16% of total GWP in the beef

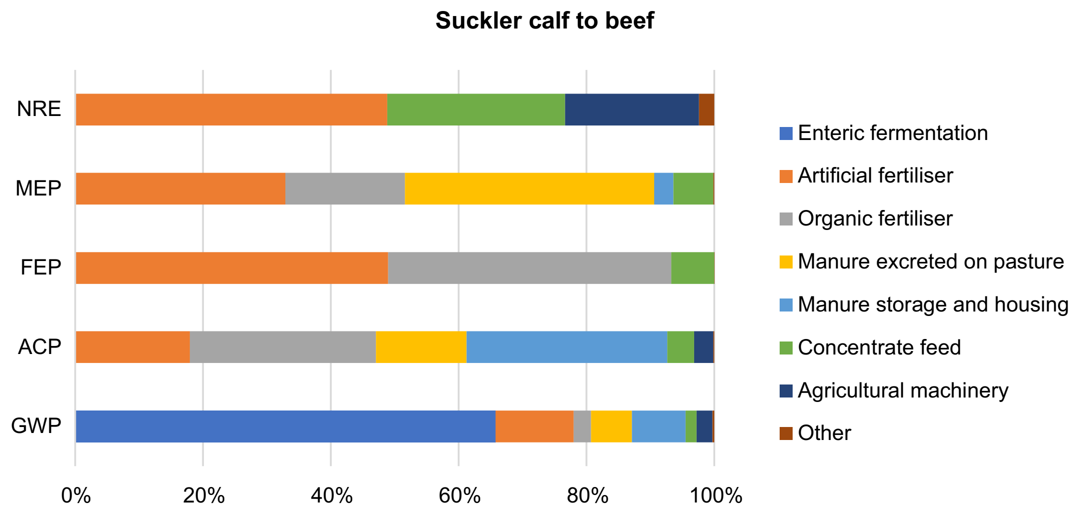


**Figure 5.1. Contribution analysis of midpoint impact categories for an average grass-based suckler calf to beef production system in Ireland. NRE = NRE depletion. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

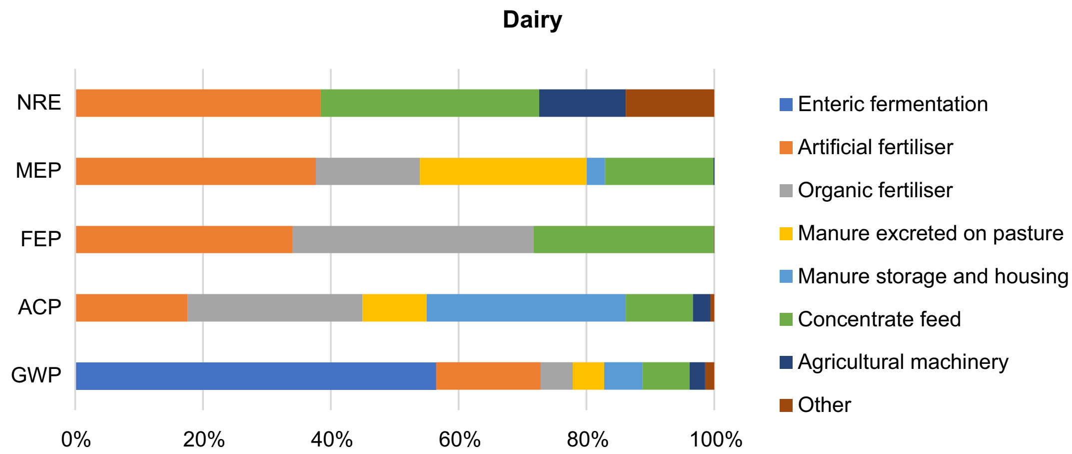


**Figure 5.2. Contribution analysis of midpoint impact categories for an average grass-based dairy production system in Ireland. NRE = NRE depletion. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

system and 21% in the dairy system. Soils and the manufacture of fertilisers were the main sources of $N_2O$. Synthetic fertilisers were also a major contributor to $CO_2$ emissions, along with feed imports, particularly soybean, and agricultural machinery. Total GWP results for both cattle systems were considerably lower than the global averages estimated by Opio *et al.* (2013), i.e. 2.8 t $CO_2$-eq/t FPCM and 67.8 t $CO_2$-eq/t CW, and similar to or below the European results reported in the literature (Baldini *et al.*, 2017; Poore and Nemecek, 2018). Relatively long grazing seasons (7–9 months) in the average Irish beef and dairy systems, combined with highly digestible grasses and excellent animal genetics, are likely to have resulted in total GWP being less than the international averages. The outcomes for GWP were also in line with GWP results reported by Leip *et al.* (2010) for EU and Irish cattle systems. These authors, in contrast to Opio *et al.* (2013), took into account the effect of C sequestration. The influence of C sequestration on GWP highlights the importance of reporting assumptions around this process (O'Brien *et al.*, 2023).

ACP and eutrophication potential (EUP) were at the lower end of the range of reported outcomes for cattle systems (e.g. de Vries M. *et al.*, 2015; Baldini *et al.*, 2017). The total ACP for the suckler calf to beef system was 157 mol $H^+$/t CW (Table 5.3), which, on a $SO_2$-eq basis, was similar to the minimum ACP reported by de Vries M. *et al.* (2015). This study highlighted variability in ACP (190–362 kg $SO_2$-eq/t CW) and EUP (35–393 kg $PO_4$-eq/t CW) across LCA studies of suckler beef production. The total EUP of the suckler calf to beef system was slightly less than 95 kg $PO_4$-eq/t CW. For the average conventional dairy system, total EUP and total ACP were lower than the averages Baldini *et al.* (2017) reported for dairy LCA studies. Like de Vries M. *et al.* (2015), Baldini *et al.* (2017) found substantial variability in the total ACP and EUP of milk. This variability was caused by differences in farm productivity and LCA calculations, e.g. emission factors, which implies that caution is required when comparing outcomes across agricultural LCA studies (O'Brien *et al.*, 2023).

As described in O'Brien *et al.* (2023), EUP was further evaluated under two subcategories: marine and freshwater. The MEP and FEP of conventional cattle systems were comparable to or lower than previously reported figures (Chobtang *et al.*, 2016; Famiglietti *et al.*, 2019; Payen *et al.*, 2020), albeit few studies have reported these metrics for cattle systems. $NO_3^-$ emissions related to synthetic fertilisers and organic manure caused 75–85% of MEP in conventional beef and dairy systems (Figures 5.1 and 5.2). P loss from these sources accounted for > 70% of FEP in both production systems. $NH_3$ loss associated with cattle housing, grazing and fertilisers contributed to MEP, and $NH_3$ was the principal acidifying pollutant. The contribution of key pollutants and sources to ACP, FEP and MEP in the average conventional systems was largely in line with the previous findings (de Vries M. *et al.*, 2015; Chobtang *et al.*, 2016; Baldini *et al.*, 2017; Payen *et al.*, 2020). The outcomes for land occupation and NRE per tonne of CW or FPCM were consistent with the findings in these studies. Permanent pasture dominated land use in the average beef and dairy systems, making up 88–97% of the total area. Land for concentrate feed occupied most of the remaining area and was the second largest user of NRE (28–34%), after N fertiliser production (38–50%). On-farm machinery operations were a relatively minor consumer of NRE.

### 5.2.2 *Mixed grass–white clover swards*

Incorporating white clover into ryegrass swards generally improved the productivity and resource use efficiency of conventional cattle farming. Relative to the average dairy system, the legume increased milk yield per cow by 7% and reduced the use of synthetic fertiliser N by 43%, to 105 kg N/ha. Compared with the conventional suckler calf to beef system, GWC swards caused a similar relative rise in beef output per hectare and lowered synthetic fertiliser N use by 33 kg N/ha. Gains in beef output were mainly due to increases in stocking rate. Improvements in animal performance in the GWC sward-based cattle systems were comparable to the findings of Egan *et al*. (2018) and Moloney *et al.* (2018). The drop in N fertiliser use in both of these systems was also in line with the findings of Egan *et al*. (2017, 2018) for grass-based ruminant systems (O'Brien *et al*., 2023).

In agreement with Yan *et al*. (2013) and Herron *et al.* (2021b), switching from grass-only swards to GWC swards reduced GWP and NRE depletion per hectare and per unit of product (Figures 5.3–5.6). GWC swards decreased GHG emissions and NRE depletion by partially replacing energy-intensive fertiliser N with biological N. The N fixed in the clover root nodules decreased NRE depletion by 14–18% relative to the average cattle systems. It had a greater mitigating impact on the total GWP of dairy production than on the total GWP of beef production because the former system was more reliant on synthetic fertiliser N. Biological N fixation also mitigated the total ACP of conventional cattle systems by 4–5% (O'Brien *et al.*, 2023).

As explained in O'Brien *et al*., (2023), replacing synthetic fertiliser N with biological N from white clover had little effect on the FEP of the average beef and dairy systems. However, similarly to the findings of Herron *et al.* (2021b), it increased MEP, particularly in the beef system, because white clover fixed more N than it replaced. Ledgard *et al.* (2009) noted that white clover had a mixed effect on N leaching and reported that N leaching increases exponentially with increasing N inputs, regardless of form, organic or synthetic. GWC swards increased total N input for the beef and dairy farms, which is likely to explain the rise in these systems' total MEP. Greater N in GWC swards tends to improve herbage quality and, thus, animal

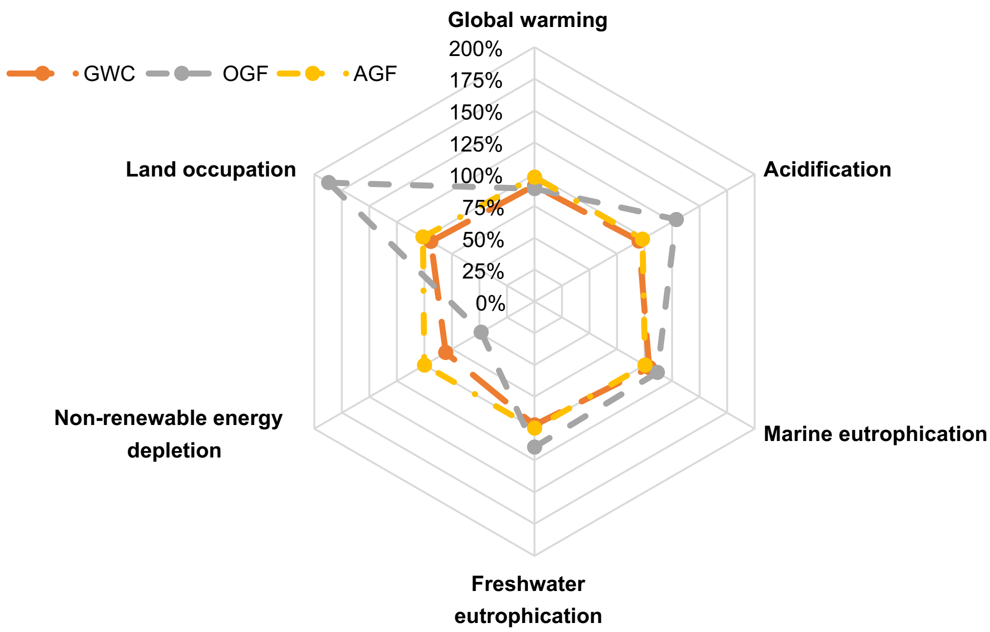


**Figure 5.3. Effect of diversification options on the potential environmental impacts related to 1 t of FPCM produced on an average grass-based dairy farm in Ireland, 2017–2019. The potential impacts of diversification were scaled against a conventional dairy system. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

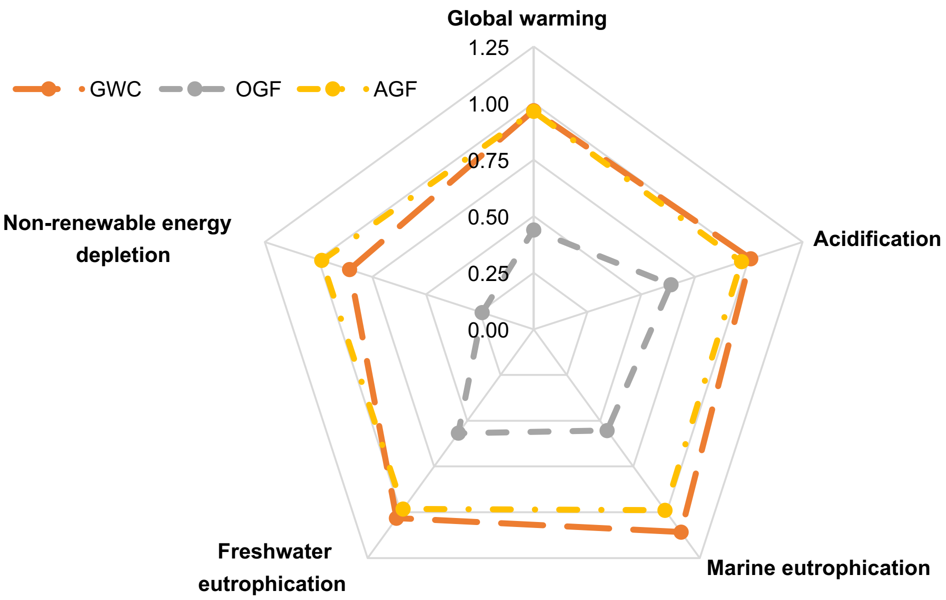


**Figure 5.4. Effect of diversification options on the potential environmental impacts related to 1 ha of land occupied by an average grass-based dairy farm in Ireland, 2017–2019. The potential impacts of diversification were scaled against a conventional dairy system. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

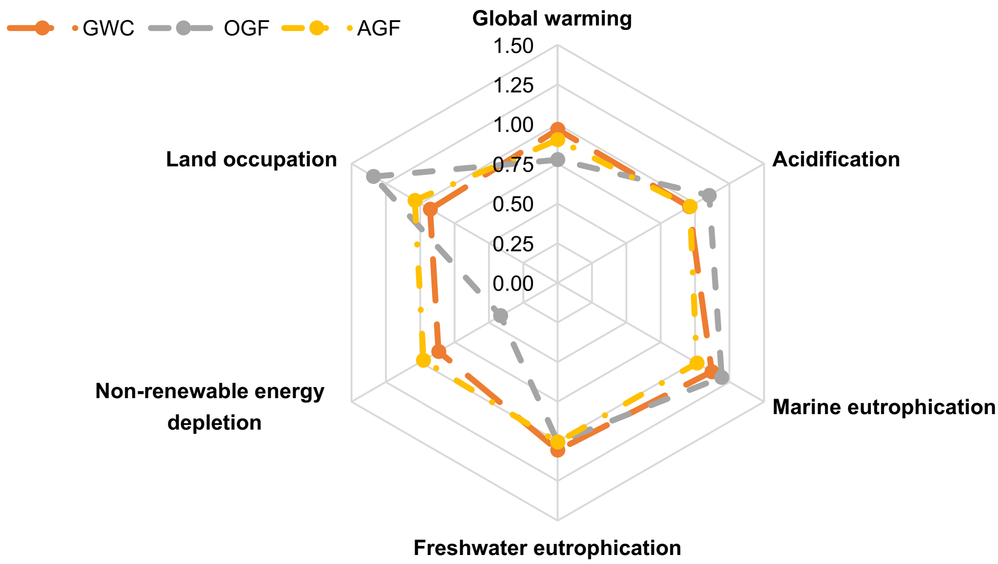


**Figure 5.5. Effect of diversification options on the potential environmental impacts related to 1 t of CW produced on an average grass-based suckler calf to beef farm in Ireland, 2017–2019. The potential impacts of diversification were indexed against a conventional suckler calf to beef system. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

performance. Clover is also more digestible than ryegrass, and Egan *et al*. (2017) showed that GWC swards produce more herbage than ryegrass swards in the second half of the growing season. Combining these benefits for GWC swards in the conventional cattle systems reduced the area required for a tonne of beef and milk, but increased total ACP and total EUP per hectare of land occupied.

### 5.2.3 *Organic farming*

Changing the conventional spring-calving dairy farm to an organic system decreased milk output by 57%,

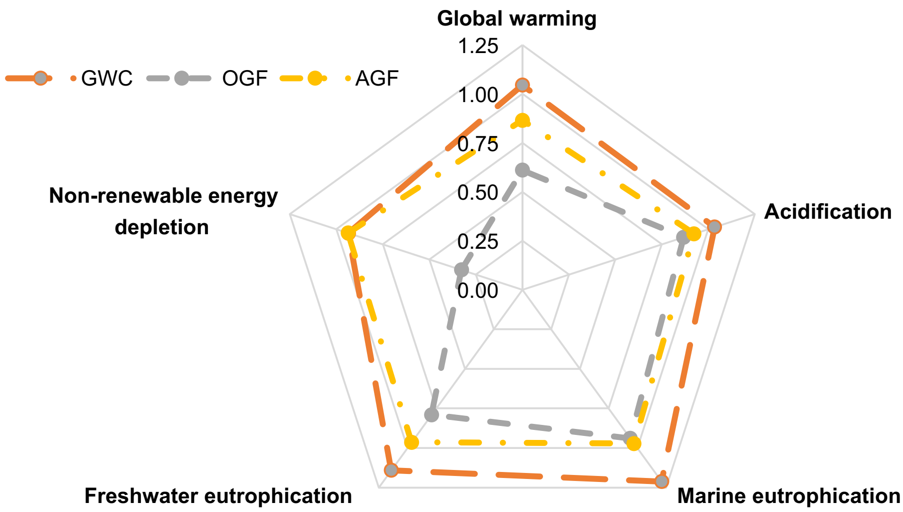


**Figure 5.6. Effect of diversification options on the potential environmental impacts related to 1 ha of land occupied by an average grass-based suckler calf to beef farm in Ireland, 2017–2019. The potential impacts of diversification were indexed against a conventional suckler calf to beef system. Reproduced from O'Brien *et al.*, 2023; licensed under CC BY-NC-ND 4.0 DEED (https://creativecommons.org/licenses/by-nc-nd/4.0/).**

to 4062 kg milk/ha. Switching from conventional suckler beef production to organic production reduced beef sales from 241 to 190 kg CW/ha. Extensive farming and poorer animal performance, especially in the organic dairy system, caused declines in milk and beef production. Unsurprisingly, extensification positively influenced the absolute environmental impact of organic beef and dairy systems. These farms consumed the least amount of NRE and had the lowest total GWP, ACP and EUP per hectare (Figures 5.4 and 5.6). Similarly to Mondelaers *et al.*'s (2009) and Tuomisto *et al.'s* (2012) meta-analyses of agricultural systems, the principal reasons for low NRE use and absolute environmental impacts in the organic farms were (1) no synthetic fertilisers and pesticides were applied and (2) concentrate feeding levels and stocking rates were lower than conventional systems (O'Brien *et al.*, 2023).

According to O'Brien *et al.* (2023), in contrast to environmental impacts per unit of land, OGF had a mixed effect on the resource use and environmental impacts of agricultural products (Figures 5.3 and 5.5). Organic cattle systems had a similar or greater total ACP, MEP, FEP and land use than average conventional farms on a product basis. Total NRE depletion and total GWP per tonne of FPCM and per tonne of CW were lower in the organic systems than in conventional farms. C sequestration in organic farms was more than double the conventional systems when assessed per unit of product, which resulted in a lower GWP for organic milk. The C sequestration rate did not differ in organic and conventional bovine systems on an area basis, as there was limited research to suggest otherwise. This assumption may have led to an underestimate of the total GWP of organic products, partly because including C sequestration favours low-yielding systems (Plassmann, 2012).

Increasing the share of roughage in the diet of dairy cows raised $CH_4$ emissions, resulting in a greater total GWP for organic milk than conventional milk when C sequestration was excluded. The conventional beef system fed 6% more concentrate supplement than the organic system, but released more $CH_4$ per tonne of CW. The diverging findings for beef and dairy were partly caused by a smaller difference in concentrate feeding rates for the latter form of cattle farming. Storing solid instead of liquid manure in organic systems also contributed to lower $CH_4$ emissions for the organic beef system. de Vries W. *et al.* (2015) did not report lower $CH_4$ emissions from manure stored in organic systems but did show that organic beef systems had a lower GWP per unit of product than conventional farms. Switching to solid manure had the opposite effect on the total ACP of organic dairy and beef products, as the change increased $NH_3$ loss associated with manure (O'Brien *et al.*, 2023).

Organic bovine systems principally rely on nutrients from animal manures and N fixed by white and red clover. Matching organic nutrient supply with plant nutrient demand is challenging because the nutrient content of organic inputs is often not well known, and the availability of organic nutrients is primarily governed by unpredictable environmental conditions (Clark and Tilman, 2017). In addition, the rate of nutrient release from organic inputs is slow relative to synthetic fertilisers. Temporal mismatches in nutrient supply and demand resulted in low forage yields in the organic bovine systems and led to less efficient use of nutrients in these systems relative to conventional farms. Consequently, organic beef and dairy systems required more land than conventional farms to produce the same output level and, similarly to the results of Tuomisto *et al.* (2012), had a greater EUP and MEP per unit of product (O'Brien *et al*., 2023).

### *5.2.4 Agroforestry*

As reported by O'Brien *et al*. (2023), silvopasture bovine and dairy systems caused a slight (1–2%) increase in herbage utilisation and livestock production. An extension of the grazing season explained the productivity gains. In terms of output, the silvopastoral beef system produced 4% less CW than the national average, and the silvopastoral dairy system yielded 2% less milk than the average, notwithstanding the extra herbage utilised by cattle in silvopasture. The main reason for the absence of a production benefit for the AFS systems was that herbage yield declined on the part of the farm under silvopasture. Grazing cattle in silvopasture instead of grassland decreased NRE depletion by replacing fossil fuels with renewable energy from tree thinnings. This finding agrees with Rivera *et al*.'s (2016) results for silvopastoral dairy systems. However, the 1–3% improvement in NRE depletion for silvopastoral bovine systems in this study was much lower than the 37% gain reported by Rivera *et al*. (2016). In Rivera *et al*.'s (2016) study, allocating a large portion of the silvopastoral systems to permanent pastures is likely to have caused the relative divergence. Moreover, synthetic N use was increased on the permanent pasture area of the farm to make up for the deficit in silvopasture. The extra N increased herbage yields in permanent pasture, which resulted in no difference in land occupation per unit of product between the silvopastoral and conventional bovine systems.

Regarding environmental impacts, AFS had little or no impact on total MEP and FEP, but tended to improve ACP and GWP. The total ACP and GWP of the silvopasture beef system were 4–8% lower than the average conventional dairy farms on an area and product basis. These impacts for the silvopasture dairy system were about 2–3% lower than for the average milk producer. The improvements in the ACP and GWP impacts in the AFS systems were primarily driven by the longer grazing season. Extended grazing decreased slurry storage times, which, consistent with the findings of Montes *et al.* (2013), decreased $NH_3$ and GHG losses from manure. Reducing slurry storage decreased farm machinery use and related $CO_2$ emissions. Similarly to the findings of Schils *et al.* (2005), a shorter storage period negatively affected N emissions associated with cattle grazing, but this was more than compensated for by the reduction in housing-related emissions. In addition, shortening the housing period also reduced grass silage demand, further decreasing machinery use and $CO_2$ losses. Replacing grass silage with pasture also reduced $CH_4$ emissions, as grazed grass is generally more digestible than silage and thus less conducive to methanogenesis (O'Brien *et al*., 2023).

AFS sequestered 0.8 t C/ha per year over two rotations. C sequestration offset GHG emissions from silvopastoral beef and dairy systems by 32% and 17%, respectively. The amount of C sequestration in AFS was considerably greater, i.e. almost 60% more than the quantity of C removed in permanent pasture. Extra C sequestration in AFS accounted for over half of the decrease in the total GWP of silvopastoral beef and dairy systems. The calculated rate of C sequestration in AFS is a relatively conservative estimate. McAdam (2020) and McAdam *et al*. (2018) reported that silvopasture in Northern Ireland sequesters approximately 3.2 t C/ha per year and has the potential to deliver a C-neutral livestock system. Adopting the same rate of C removal in this study would have reduced the total GWP of the silvopastoral beef system a further 40%, to 11 kg $CO_2$-eq/kg CW, and to reduce the GWP of the silvopastoral dairy system by a further 10%. Allocating a greater share of the beef and dairy farms to silvopasture would bring both farms closer to C neutrality, but this would lead to inevitable trade-offs related to farm performance, resources and environmental outcomes. Balancing these trade-offs will require a multidisciplinary approach.

# 6 General Discussion

## 6.1 Farmers' Motivations for Diversifying and Their Profile

The majority of farmers interviewed contended that a sense of stewardship towards the natural environment underpinned their decision to undertake pro-environmental diversification. This finding reinforces prior research analysing the values of environmentally conscious farmers, with such farmers typically displaying conservationist as opposed to productivist ideals (Mills *et al.*, 2013). While financial benefits (e.g. monetary incentives, reduced production costs, higher prices of food produced) were referenced by farmers interviewed in the current study, these sentiments emerged as largely secondary to pro-environmental values.

Interviews with farmers conducted as part of the CattleDiVersa project revealed that the values important to farmers who implemented pro-environmental diversification focused on several themes, including the environment, the economy, autonomy and society. However, profit maximisation was considered a relatively less important value. This profile of farmers corresponds to the profile of new peasants characterised by van Ploeg (2018). Both the social and academic conceptions of what a peasant is extend beyond that of someone just involved in agricultural activities. According to van Ploeg (2018), being a peasant is more than just being a producer of food or other agricultural products. Peasants are involved in agriculture because it offers them a livelihood that provides them with employment, an income, an identity, a place to belong (which is also a relatively safe and clean space for their children to grow up in), social networks and, probably, some level of dignity and a feeling that they are part of a more comprehensive whole. In the past, peasants have often been wrongly perceived as "the embodiment of backwardness and poverty" (van Ploeg, 2018); however, nowadays, peasant farming can be highly productive and cost-effective and plays a vital role in protecting biodiversity, natural landscape and the countryside (Niska *et al.*, 2012).

Peasant farming is often represented in scientific literature as being in opposition to entrepreneurial farming, which concerns big specialised farms that are financed through the banking system and are highly dependent on external inputs. Thus, entrepreneurial farming has been proven to be less resilient and more vulnerable to price volatility than smaller, more flexible, peasant farms with higher margins. Consequently, an increasing number of frustrated and disappointed producers have started to question the entrepreneurial model and are, in turn, moving towards the independent peasant model, i.e. the new peasant model (van Ploeg, 2018). The strategies utilised by participants in this study to overcome the challenges posed by the global food system correspond with those defined by van Ploeg (2018) for new peasant farmers. They include reducing the use of external inputs and increasing the multifunctionality of the farms, and the participants share the same attitude towards lobbies and big companies. The profile of farmers participating in this study also corresponds with the profile of successful and innovative young farmers from Italy presented by Milone and Ventura (2019).

## 6.2 Farmers' Experiences and Challenges

### *6.2.1 Education*

Lack of formal educational opportunities (e.g. third-level courses) available to current and prospective pro-environmental farmers to further their knowledge also emerged as a common theme among study participants. While exceptions were cited, farmers claimed that the availability of third-level educational courses (undergraduate/postgraduate) in organic agriculture and other relevant institutional, educational channels were limited or necessitated travel abroad (particularly in the case of Ireland). As informal educational channels developed by members of the pro-environmental and OGF community (e.g. online conferences, farm walks) often served as the only means of knowledge acquisition other than self-learning, these activities are of potential importance to future pro-environmental agricultural policies.

### 6.2.2 Availability of land

As described in Mooney *et al*. (2023), land availability and rules and regulations governing land use were cited as challenges by farmers, and such challenges are also reflected in literature across Europe and the wider world (Lakner *et al.*, 2018; Zollet and Maharjan, 2021). One of the most frequently cited grievances of Irish and French farmers in the current study concerned flaws within existing policies relating to the Common Agricultural Policy (CAP). Respondents believed that loopholes in regional and national environmental strategies enable conventional farmers adopting minimal pro-environmental measures to unfairly benefit from financial incentives, thus diminishing the efforts of licensed organic and pro-environmental farmers. As this issue has been repeatedly discussed over the last decade within agricultural valuation and policy studies, it is likely to form a key strand of upcoming discourses concerning the present iteration of the CAP (Pike, 2013; O'Rourke *et al*., 2016).

## 6.3 Research on Pro-environmental Diversification

The results of the literature review indicate that implementing meaningful biodiversity mitigation strategies such as ESMPs depends on the scale at which these measures are applied (Baker *et al.*, 2012). For example, despite frequently positive responses from birds to ESMPs, overall, populations of examined species continue to decline, with a significant increase in the uptake of selected ESMPs thus required to assist in reversing this trend (Baker *et al.*, 2012).

As summarised in Markiewicz-Keszycka *et al*. (2023), according to several studies identified in the current review, SNRG and mixed grazing would offer "win–win" solutions for biodiversity conservation, enhancing animal productivity and reducing GHG emissions (Fraser *et al.*, 2007, 2013, 2014; Richmond *et al.*, 2014). However, the implications of these systems have been studied by only two research teams, both from the UK, and in both cases were limited to mixed grazing of cattle and sheep. MSSs offer relatively low-input, high-impact potential to diversify plant species within pastures, attract more fauna, decrease chemical usage, including fertilisers, and reduce N excretion from cattle. Most of the identified research on MSSs (87.5%) originated from New Zealand; however, the topic is now also increasingly studied in Ireland and the UK. Studies were limited to dairy cows and did not include beef cattle. More information on the impact of MSSs on biodiversity, animal welfare, chemical fertiliser and herbicide use, and nutritive values of plants over time, gathered through long-term grazing studies, is required to improve current knowledge on their applications and limitations (McCarthy *et al.*, 2020).

Results from the current study would seem to confirm that organic systems on grass-based dairy farms have a positive impact on biodiversity and animal welfare compared with conventional systems (Langford *et al.*, 2009; Rutherford *et al.*, 2009; Gabriel *et al.*, 2010; Power and Stout, 2011; Power *et al*., 2012). However, research on this topic is limited, with just seven studies identified over the 20-year review period. To fully appraise the potential role of OGF in producing sustainable, biodiversity- and climate-friendly grass-based milk and beef, more research on the impact of organic systems on the environment, biodiversity, animal welfare and product quality is required (Markiewicz-Keszycka *et al*., 2023).

AFS represents another emerging agricultural system that remains understudied, with only two studies, both from New Zealand, providing evidence of the effects of tree plantations on pastures (Markiewicz-Keszycka *et al*., 2023). Meanwhile, according to McAdam *et al*. (2006), incorporating AFS into pasture-based ruminant production improves its sustainability and contributes to the growth of rural economies (McAdam *et al*., 2006). However, establishing silvopasture requires several years before cattle can be (re)introduced. Therefore, studies and solutions for different stages of implementation of this system are needed. Building and strengthening farmer–researcher networks and collecting data from multiple farms will be critical to future research in AFS (Niggli *et al.*, 2017).

## 6.4 Environmental and Economic Implications of Pro-environmental Diversification

Diversification options had contrasting effects on conventional grass-based cattle farms' resource use and environmental impacts. Generally, diversifying into silvopasture AFS and OGF had a positive influence on environmental impacts on an area basis, but the latter decreased milk and beef production considerably and increased land occupation compared with conventional farming. OGF increased the environmental impacts of dairy and beef products, as more land is used for agriculture. However, this diversification strategy reduced NRE depletion, as no fertilisers and pesticides were applied on organic farms. Silvopasture also decreased reliance on fossil fuels, and partial adoption tended to mitigate environmental impacts, particularly GWP, per unit of product. Herbage and animal productivity were maintained when silvopastoral and conventional cattle systems were combined, but full conversion to silvopasture increases land occupation and tends to compromise cattle production (O'Brien *et al*., 2023).

As reported by O'Brien *et al*. (2023), a relatively simple diversification strategy, altering sward type, decreased land occupation and NRE depletion by replacing fertiliser N with N from a legume, and improved productivity. Decreases in synthetic fertiliser N and productivity gains usually reduce environmental impacts per unit of product and together facilitate the sustainable intensification of agricultural systems. Improving productivity decreases environmental losses per output unit by diluting maintenance requirements, but often has the opposite effect when losses are evaluated on an area basis. For example, in this study, GWC swards were more productive than ryegrass swards, which resulted in a rise in total ACP and EUP per hectare for cattle farms. Land spared by productivity improvements could be used to restore or create wetland and woodland habitats that mitigate pollutants from cattle farming. Rewetting peat soils, protecting wetlands and waterways, and protecting woodland or creating new woodland habitats constitute effective ways to encourage and support biodiversity on the farm. Likewise, ecosystems provide key habitats for many plants and animals, help to store C, store and filter water, mitigate the effects of droughts and floods, and enhance the landscape's natural beauty. These habitats can compensate for greater emissions from farmland and potentially decrease the overall environmental impact of cattle production. However, the effectiveness of this nature-based solution depends on the demand for milk and beef, which could be evaluated through a future consequential LCA.

Markiewicz-Keszycka *et al*. (2023) reports that it is anticipated that the inclusion of pro-environmental diversification and reduction of chemical inputs will decrease feed production and lower animal productivity and, consequently, farmers' income (Zhou *et al.*, 2020; Brown *et al.*, 2021; Kragt *et al.*, 2021); however, these concerns were seldom addressed in identified literature. Two studies conducted a cost analysis of proposed diversification actions, with results indicating that the inclusion of trees on the pastures and replacement of grass silage with cereal silage had either a positive or neutral effect on overall production and farmers' income (Dodd *et al.*, 2008; Peach *et al.*, 2011); however, more studies on the profitability of silvopastoral systems in Irish conditions are needed to support Dodd *et al.*'s (2008) findings. According to Niggli and Riedel (2020), reports on polycultures implemented in different parts of the world indicate that these systems are characterised by 40–145% higher yields than sole cropping. Similarly, conservation grazing and utilisation of SNRG in summer allow for the production of winter feed in the form of silage or hay from permanent pastures, adding to the profitability of this practice (Fraser *et al*., 2013).

Moreover, most biodiversity-rich lands are wetlands, moorlands, woodlands, hedgerows and areas of low agricultural value. Thus, according to Delaby *et al.* (2020), biodiversity protection does not adversely affect farms' productivity and profitability. More case studies demonstrating the financial benefits of pro-environmental diversification reaching beyond financial incentives are needed to improve the current understanding of the economic consequences of these actions for both individual farmers and society (Markiewicz-Keszycka *et al*., 2023).

# 7 Conclusions and Recommendations

Given the importance of environmental sustainability within dairy and beef production, holistic studies investigating management practices that can potentially decrease GHG emissions and strengthen biodiversity and ecosystem services on dairy and beef farms are urgently needed. The outcomes of the present study highlight that pro-environmental diversification represents multiple disciplines that encompass agricultural sciences, food sciences, environmental sciences, sociology and economics. However, research results are frequently fragmented, focusing on only one or two impacts. For example, ESMPs have been studied mainly from a biodiversity perspective, leaving animal welfare, GHG emissions and animal productivity unexplored. This may be a result of the nature of the funding available for such research; however, studying the solutions from only one perspective (agriculture/ecology/food science) often does not cover the entire spectrum required for meaningful transformation. Addressing all three pillars of sustainability, namely social equity, economic viability and environmental protection, is thus crucial to generate positive, acceptable change among farmers and consumers. Researching several impacts concurrently would show diversification trade-offs more comprehensively.

The results of the literature review also indicate that, because many research funders and programmes provide funding for a maximum of 4 or 5 years, the time required to observe biodiversity changes represents another (inherent) limitation. Several authors have stated that study periods are typically too brief to monitor the long-term impacts of proposed diversification and amended management practices (Davey *et al*., 2010; Baker *et al*., 2012).

The environmental impact of the diversification options investigated in this study was tested on conventional grass-based farms that are representative of common cattle production systems in Ireland. In reality, there is not a single type of conventional cattle farm but a wide range of systems with different management practices. The environmental impact and resource use of cattle farms usually depends more on producers' management decisions than on their general production system. Cattle farmers who choose to diversify into AFS, organics or mixed swards may therefore experience different environmental and resource outcomes. Examining these practices on more farms with different management regimes would provide better insight into the environmental benefits and drawbacks of diversification on individual cattle farms. Thus, more research is needed on the effect of combining different diversification options with C sequestration.

Including farmers in the scientific process and fostering interdisciplinary systemic approaches would significantly benefit the design of solutions-oriented agroecological studies.

This study has shown that European farmers who have implemented pro-environmental diversification follow the new peasant farming model as opposed to the entrepreneurial model promoted by the CAP. It is important to promote the attitudes of peasant farmers through policies because they lead to the creation of a resilient agricultural sector and contribute to the environmental and climate objectives of the EU. Broader knowledge about European farmers' attitudes towards the peasant model is needed to accurately target this group, which has a high potential to transform the European food system.

Farmers, policymakers and consumers play an important role in redesigning future food systems. However, top-down measures are frequently limited to financial incentives and lack educational, communicative interventions. Knowledge of farmers' values and their motivations for pro-environmental diversification is limited. Therefore, validating existing claims about farmers' acceptance of and motivations for pro-environmental diversification is challenging. Meanwhile, it has been documented that many farmers are genuinely inclined to farm in harmony with nature and may be agreeable to adopting environmental management measures where pre-existing values and motivations are appropriately addressed (Mills *et al*., 2013).

Currently, non-governmental organisations, pro-environmental farmers' associations and OGF associations are usually the main contributors to promoting knowledge on agroecology and nature-inclusive farming practices. The increased availability and incentivisation of pro-environmental agricultural courses through farming advisory boards, non-profit organisations and agricultural colleges is likely to be essential in encouraging the future uptake of pro-environmental agricultural diversification activities.

Even though emissions from conventional grass-based dairy and beef production practised in Ireland are similar or below EU averages, high stocking rates and large amounts of N fertilisers used to produce grass negatively impact biodiversity and the environment. Advisory and scientific bodies should prioritise the development of practical farming solutions based on circular economies and custodianship. Accordingly, increased financial support from public funding institutions and the private research and development sector is required. Furthermore, additional strategies are necessary to increase consumers' awareness of the impact of intensive grass-based dairy and beef systems on biodiversity and climate change to motivate their sustainable choices and behaviours.

It is important to acknowledge that 79.3% of the farmers interviewed in this study farmed in accordance with the principles of organic agriculture and were certified organic. These results indicate that participation in the organic scheme is an important driver that facilitates the implementation of pro-environmental measures on the farm. The European Green Deal has identified organic agriculture as an important means to increase the sustainability of agriculture. Thus, an increased uptake of OGF will result in higher pro-environmental diversity and will increase the self-sufficiency of farms, which is becoming more essential in the context of disrupted supply chains and the current crises in Europe caused by the COVID-19 pandemic and the Russian invasion of Ukraine.

As farmers interviewed in this study indicated, additional financial instruments and transparent regulations based on results-based schemes (such as current agri-environmental schemes under the new CAP strategic plan, e.g. the Agri-Climate Rural Environment Scheme) will encourage and facilitate the uptake of pro-environmental actions. Furthermore, future agricultural policies aiming to transform the agricultural system into a more sustainable one should be centred around the welfare of people and nature, rather than the personal success of the individual farmer.

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# Abbreviations

| | |
|---|---|
| **ACP** | Acidification potential |
| **AFS** | Agroforestry |
| **CAP** | Common Agricultural Policy |
| **CW** | Beef carcass weight |
| **DM** | Dry matter |
| **ESMP** | Environmentally sensitive management practice |
| **EUP** | Eutrophication potential |
| **FEP** | Freshwater eutrophication potential |
| **FPCM** | Fat- and protein-corrected milk |
| **GHG** | Greenhouse gas |
| **GLAS** | Green Low-Carbon Agri-Environment Scheme |
| **GWC** | Grass–white clover |
| **GWP** | Global warming potential |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **ISO** | International Organization for Standardization |
| **LCA** | Life cycle assessment |
| **MEP** | Marine eutrophication potential |
| **MSS** | Multispecies sward |
| **NFS** | National Farm Survey |
| **NRE** | Non-renewable energy |
| **OGF** | Organic farming |
| **OR** | Odds ratio |
| **SD** | Standard deviation |
| **SNRG** | Semi-natural rough grazing |
| **WP** | Work package |

# Appendix 1

**Table A1.1. Beliefs relating to pro-environmental farming**

| Variable | Response category | Score |
|---|---|---|
| I believe that environmentally friendly farming will lead to less money for farmers | Likely | 0 |
| | Neither likely nor unlikely | 1 |
| | Unlikely | 2 |
| I believe that environmentally friendly farming will lead to an improved economy | Likely | 2 |
| | Neither likely nor unlikely | 1 |
| | Unlikely | 0 |
| I believe that environmentally friendly farming will lead to a better society | Likely | 2 |
| | Neither likely nor unlikely | 1 |
| | Unlikely | 0 |
| I believe that environmentally friendly farming will lead to a better international reputation for farming | Likely | 2 |
| | Neither likely nor unlikely | 1 |
| | Unlikely | 0 |
| I believe that environmentally friendly farming will lead to less food for everyone | Likely | 0 |
| | Neither likely nor unlikely | 1 |
| | Unlikely | 2 |
| I believe it is possible to farm and protect the environment at the same time | Agree | 2 |
| | Neither agree nor disagree | 1 |
| | Disagree | 0 |
| As a farmer, I consider myself to be a guardian of the countryside | Agree | 2 |
| | Neither agree nor disagree | 1 |
| | Disagree | 0 |
| I believe that agriculture contributes to a reduction in native wild plants | Agree | 2 |
| | Neither agree nor disagree | 1 |
| | Disagree | 0 |
| I believe that a decrease in pollinating insects such as bees will have an impact on my farm | Agree | 2 |
| | Neither agree nor disagree | 1 |
| | Disagree | 0 |
| I consider the issue of climate change to be | Important | 2 |
| | Moderately important | 1 |
| | Unimportant | 0 |

**Maximum score per individual belief type = 2; maximum overall belief score = 20.**


| Variable | Mean score | Std. dev. | Median score | Test statistic | *P* value |
|---|---|---|---|---|---|
| **Gender** | | | | 0.986 [1] | 0.324 |
| Male | 66.3 | 8.5 | 70.0 | | |
| Female | 68.0 | 6.3 | 70.0 | | |
| **Age** | | | | 5.974 [2] | 0.309 |
| 18-25 years | 65.9 | 7.4 | 65.0 | | |
| 26-35 years | 65.8 | 9.0 | 65.0 | | |
| 36-45 years | 65.8 | 9.2 | 65.0 | | |
| 46-55 years | 67.3 | 6.7 | 70.0 | | |
| 56-65 years | 68.0 | 8.1 | 70.0 | | |
| ≥ 66 years | 68.9 | 9.6 | 72.5 | | |
| **Education** | | | | 1.177 [1] | 0.555 |
| Primary/secondary school | 67.7 | 7.6 | 70.0 | | |
| University/vocational degree | 66.5 | 8.0 | 65.0 | | |
| Postgraduate degree masters/PhD | 65.7 | 10.1 | 70.0 | | |
| **Farming type** | | | | 4.263 [2] | 0.119 |
| Beef | 67.2 | 8.3 | 70.0 | | |
| Dairy | 65.6 | 8.0 | 65.0 | | |
| Beef & dairy | 66.1 | 8.9 | 70.0 | | |
| **Organic farming** | | | | 14.673 [1] | <0.001 |
| Yes | 71.3 | 6.2 | 75.0 | | |
| No | 66.1 | 8.4 | 65.0 | | |
| **Agri-scheme participation** | | | | 3.376 [1] | 0.066 |
| Yes | 67.2 | 8.1 | 70.0 | | |
| No | 65.8 | 8.5 | 65.0 | | |
| **Land management measures** | | | | 9.313 [1] | 0.002 |
| Yes | 67.1 | 7.7 | 70.0 | | |
| No | 63.0 | 10.3 | 65.0 | | |
| **Tree and/or hedge planting** | | | | 0.069 [1] | 0.792 |
| Yes | 66.6 | 8.2 | 67.5 | | |
| No | 66.1 | 8.8 | 70.0 | | |
| **Use of low emission fertiliser** | | | | 5.295 [1] | 0.021 |
| Yes | 66.1 | 8.0 | 65.0 | | |
| No | 67.4 | 9.0 | 70.0 | | |
| **Pro-environmental motivations** | | | | | |
| ***On-farm environmental health*** | | | | 3.494 [2] | 0.174 |
| Important | 69.1 | 6.5 | 70.0 | | |
| Somwhat important | 67.1 | 6.9 | 70.0 | | |
| Unimportant | 65.5 | 7.6 | 65.0 | | |
| ***Climate change mitigation*** | | | | 3.291 [2] | 0.193 |
| Important | 70.0 | 6.4 | 70.0 | | |
| Somwhat important | 68.6 | 6.4 | 70.0 | | |
| Unimportant | 67.5 | 7.2 | 70.0 | | |
| ***Animal welfare*** | | | | 0.791 [2] | 0.193 |
| Important | 68.7 | 6.6 | 70.0 | | |
| Somwhat important | 68.1 | 7.4 | 70.0 | | |
| Unimportant | 69.1 | 6.2 | 70.0 | | |
| ***Higher price for organic products*** | | | | 2.265 [2] | 0.322 |
| Important | 68.0 | 6.9 | 70.0 | | |
| Somwhat important | 70.3 | 4.8 | 70.0 | | |
| Unimportant | 68.5 | 7.3 | 70.0 | | |
| **Pro-environmental barriers** | | | | 22.943 [2] | <0.001 |
| Lack of well-established "know-how" | 68.8 | 6.9 | 70.0 | | |
| Lower profits | 64.8 | 8.7 | 65.0 | | |
| Increased livestock diseases | 62.2 | 10.0 | 65.0 | | |
| Reduced fodder production | 65.1 | 8.5 | 65.0 | | |

Maximum belief score = 20 (100%)
Minimum belief score = 0 (0%)

[1] Mann-Whitney U test
[2] Kruskal-Wallis test

**Figure A1.1. Bivariate associations between pro-environmental belief scores and respondent characteristics.**

# An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

## Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

**Rialáil:** Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

**Eolas:** Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

**Abhcóideacht:** Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

## I measc ár gcuid freagrachtaí tá:

### Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

### Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

### Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

### Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

### Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

### Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

### Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

### Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

### Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

### Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

## Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.