A socio-economic analysis of LIFE BEEF CARBON in Ireland

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Summary

The Republic of Ireland is the largest net exporter of boneless beef in the European Union and the sixth largest in the world.

The industry produces 580,000-633,000 metric tons of beef carcass per annum, of which over 90% is exported to 45 or more countries. In 2020, the sector exported 574,000 metric tonnes of beef, despite the emergence of the COVID-19 pandemic.

The value of Irish beef exports totalled €2.3 billion last year, down 2% on 2019 because of pandemic-related disruptions in foodservice channels and challenges in regaining entry into the Chinese market.

Beef products are processed in 32 export approved meat plants. The processing of beef typically employs 15,000 people in rural areas and supports jobs in the logistics, hospitality and food services industries.

Four privately owned, multi-million euro companies namely, Anglo beef processor (ABP), Dawn Meats, Kepak and Liffey Meats slaughter approximately 75% of the cattle that pass through export plants.

The major beef plants process 1.7-1.9 million cattle annually. Finished and store cattle are procured from commercial Irish farmers. Store animals purchased by beef processors are brought to beef in finishing systems.

Beef farming is ubiquitous in Ireland. The national survey of agriculture frequently shows over 70% of farms have beef animals and approximately 78,000 of those farms are categorised as specialist producers.

Irish beef farms are relatively small, averaging 26 hectares in the specialist category. Herd size is about 64 cattle i.e. 32 livestock units. Cattle graze outdoors for 7-10 months on most beef farms. Indoors, cattle are fed conserved grass. Grass typically makes up over 90% of the animals' diet. Beef from Irish cattle meets marketing standards for grass-fed.

Family farm income for beef producers with cattle rearing as their dominant enterprise averaged €9,000 in 2020. The average income for finishing systems with selling of store cattle was just over €14,800. Innovative Irish LIFE BEEF CARBON farms performed similarly to average cattle farms in terms of costs and incomes at the start of the initiative.

Between 2016 and 2019, beef price on the 20 innovative farms dropped by an average of 12% to 1.95 kg/LW. In spite of the decline, gross margin increased by an average of 31% on 20 and net margin went up by €63/ha. The rise in margins was driven by improvements in animal and grassland productivity. Profit margins for the group in 2019 ranked in the top third nationally.

Innovative farmers, with support from advisors and researchers, created tailored plans to reduce the carbon footprint of beef. Applying the plans' actions highlighted that cattle farms can lower carbon emissions by 10%-15%, without cutting beef output, by becoming more efficient and through using scientifically proven low carbon technologies.

Increasing the efficiency of cattle production on the innovative farms caused most of the reduction in carbon footprint. Efficiency actions had negative mitigation costs i.e.

reduced carbon emissions and costs. The mitigation costs for these actions varied from €-80/t CO_2 equivalent for extended grazing to €-178/t CO_2 equivalent for increasing calving rate.

Scaling the gains in efficiency on the innovative farms to a national level would increase the sector's financial performance by about €101 million and save over 578,000 tonnes of CO_2 equivalent/year at current output levels. Additional carbon savings could be achieved by coupling efficiency gains with low emission technologies.

Urea protected with a urease inhibitor has the capacity to lower beef carbon footprint by 4-5% at relatively low cost. The mitigation potential of other proven innovations e.g., trailing shoe slurry spreaders is less than protected urea and expensive. Grant-aid is provided for certain mitigation technologies to encourage farmer adoption.

Actions to increase carbon capture i.e. sequestration such as correcting deficiencies in soil nutrients had a positive impact on the performance of the innovative farms. Gains in carbon sequestration could not be computed by farm tools, partly because of a lack of data on the effect of management on the process in Ireland. Research is currently underway to improve the quantification of carbon sequestration in farming models.

To meet Ireland's goal to become a net-zero carbon economy by 2050, the beef sector will require new carbon mitigation actions, on top of the actions applied on the innovative farms. The cost of this mitigation is likely to be high. Cattle farmers will require supports and incentives to apply cost prohibitive carbon actions.

1. Introduction

Beef farming is Ireland's largest agricultural sector in terms of numbers of farms. In the most recent farm structure survey of Irish agriculture, more than 100,000 of the 137,500 farms in operation had beef animals (Figure 1). The majority of farms that stock cattle, about 78%, are categorised as specialist beef producers by the central statistics office (CSO, 2021). The bulk of Irish beef producers own relatively small family farms and a considerable share i.e. about 40% work off-farm (Donnellan et al., 2021). At a national level, the average size of a specialist beef farm in the farm structures survey undertaken in 2016 was 26 hectares (ha), which was 6.4 ha smaller than the average for all farms (CSO, 2021). The average size of a specialist beef farm has remained relatively stable in the last decade.

Small to medium scale cattle farms are spread throughout the Republic of Ireland. They are home to several breeds of beef cattle. Almost 60% of specialist beef farms are situated in the border midland and western (BMW) region. The average herd size for farms in this region is about 45 cattle. In the south and eastern (SE) region, farms typically have twice as many cattle as the BMW average. Farms in the SE region are also larger in terms of area. The overall average for the region is 38 ha, relative to 27 ha for the BMW region (CSO, 2021). Nationally, specialist beef producers own approximately 85% of the land they farm and rent in the balance. Less than 5% of these farmers are under the age of 35 and over 55% are above the age of 55. A third of specialist producers are aged 65 and over. Beef producers in the specialist category operate a wide range of production systems. The system of beef production a farmer decides to run depends on many factors including market forces, government policies and land quality.

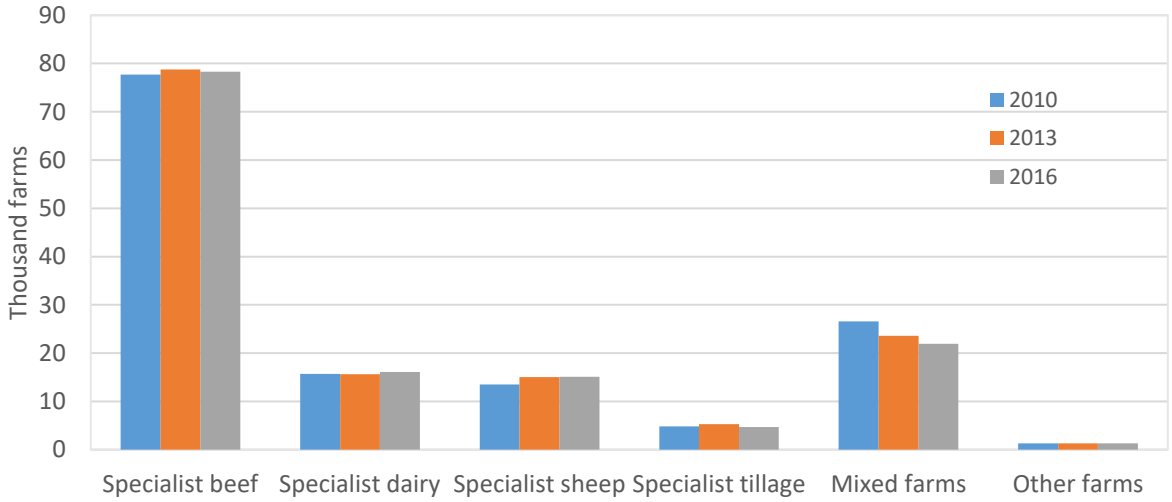

Figure 1. *Number of farms by type of specialisation in the Republic of Ireland: 2010, 2013 and 2016 (CSO, 2021).*

2. Cattle farming

Irish cattle farming systems can be classified into two broad types: Suckler beef and dairy calf to beef. The approach used to rear cattle in the calf stage largely distinguishes these systems of beef production. In suckler beef systems, a calf suckles their dam until weaning,

whereas in dairy calf to beef systems a calf is fed milk from an automatic feeder or container e.g., buckets. Most of the progeny in suckler herds are sired by late maturing breeds e.g., Limousin and Charolais. Early maturing breeds such as Hereford and Aberdeen Angus are the sire of choice in dairy calf to beef systems. Suckler beef herds dominant in the western and border regions. Dairy herds are more prevalent in the southern regions (Table 1).

Table 1. *Regional distribution of cows in the Republic of Ireland during June 2020 and percentage of beef (suckler) and dairy dams in regional populations (CSO, 2021).*

Region	Cows	Beef dam as % of cow population	Dairy dam as % of cow population
West	295	77	23
Border	277	60	40
Midland	253	49	51
Dublin & Mid-East	224	40	60
Mid-West	503	32	68
South-East	386	24	76
South-West	614	19	81
Republic of Ireland	2551	39	61

The suckler herd was smaller than the dairy herd at the end of 2020. Since the removal of milk quotas in 2015, the suckler cow population been gradually declining. Over this timescale, the number of suckler cows has dropped from 1.05 million to 922,700, while the dairy cow population has increased by 329,000 (29%) to 1.46 million (Figure 2).

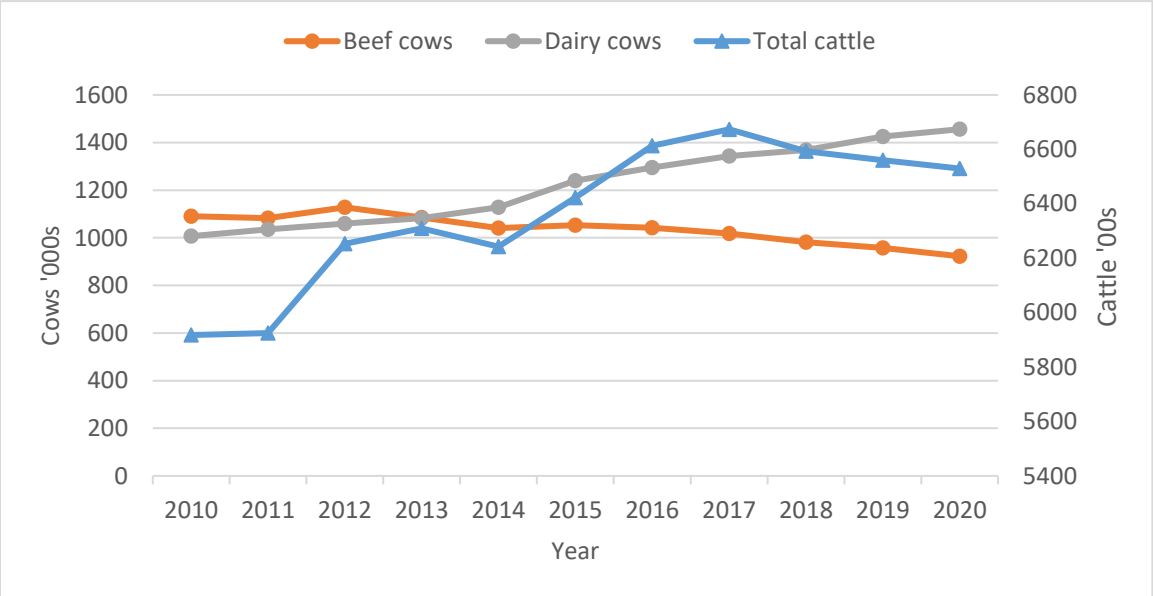

Figure 2 Temporal trends in beef cow, dairy cow and total cattle populations in the Republic of Ireland (CSO, 2021).

Notwithstanding the decline in suckler cows, the total number of cattle slaughtered has remained above 1.70 million since 2015 and reached 1.88 million in 2020. Annual exports of live cattle declined from 200,882 head to 145,570 head in the year immediately after EU milk quota abolition, before fully recovering in 2018. In 2019, live cattle exports reached 301,563 head, their highest level in 9 years, and touched their second highest level in 10 years in 2020 (DAFM, 2021a). The number and share of beef cattle from the dairy herd has increased gradually over the last 5 years (2015-2020). The share of dairy beef in the total kill is projected to continue growing as dairy expands to satisfy the rising global demand for milk products (Figure 3).

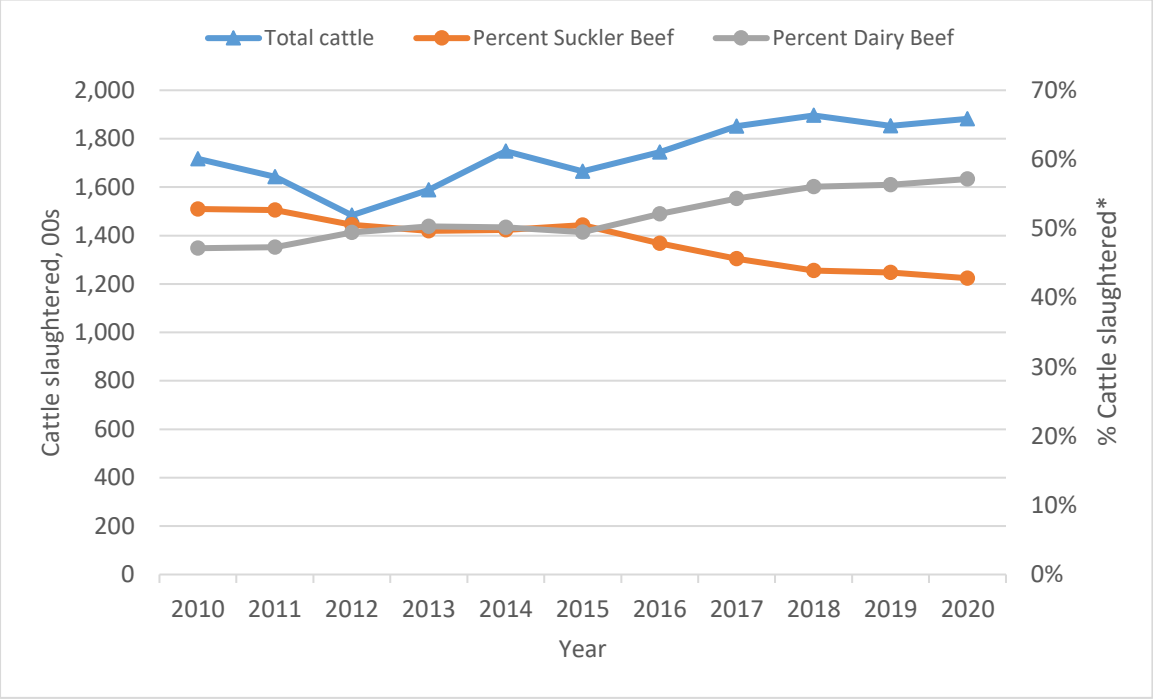

Figure 3. *Number of cattle slaughtered and percentages of cattle of suckler and dairy origin slaughtered in the Republic of Ireland between 2010 and 2020. The former was taken from official national statistics compiled by the CSO (2021). *The type of cattle processed in meat plants was estimated with statistics from the Irish Cattle Breeding Federation (ICBF, 2021).*

3. Grass-fed Beef

Grassland is the cornerstone of beef production on Irish cattle farms. About 63% of the nation is covered in grass, which is over 90% of the utilisable agricultural area (CSO, 2021); the highest proportion in Europe. Ireland's temperate maritime climate provides ideal conditions for growing and grazing grass. The length of the grass growing season ranges from 240 days in the north of the island to 300 days in the south (Figure 4).

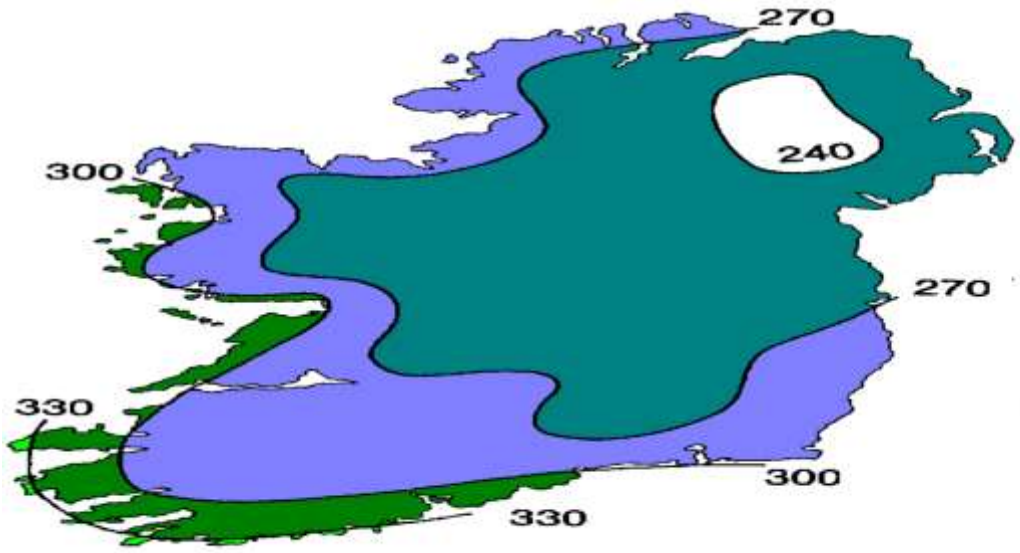

Figure 4. *Map of the median length of the grass growing season in Ireland (Connaughton, 1973)**.** Contour line labels are in days per annum.*

Grass yield is largely dependent on management and location. Innovative Irish beef cattle farmers who measured grass in LIFE BEEF CARBON recorded annual dry matter (DM) yields ranging from 6 to 11 tonne/ha at the start of the programme in 2017 (Table 2). Over the course of the project, better grassland management increased herbage production from 8 to 10 tonne DM/ha on several innovative farms. During the same period, the average grass yield for more than 200 beef farms on Pasturebase Ireland (PBI, 2021), a web-based grass recording platform, regularly exceeded 11.5 tonne DM/ha. Many of the innovative farms in LIFE BEEF CARBON have joined PBI and are aiming to replicate or surpass the herbage yields reported on the PBI platform.

Table 2. *Cohort of Irish farms participating in LIFE BEEF CARBON that measured grass production on a dry matter (DM) basis with a rising plate meter in 2017.*

Participant(s)	Province	County	Soil type(s)	Grass Yield (tonne DM/ha/year)
Sean Hayes	Connaught	Clare	Clay & loam	8.6
Nigel O'Kane	Connaught	Galway	Loam	7.8
Cathal and Peter Breen	Leinster	Wexford	Clay	11.2
Robert Abbott	Leinster	Longford	Clay & Loam	7.8
Richard Milligan	Leinster	Kildare	Clay loam	6.4
John McSweeney	Munster	Cork	Clay & Loam	10.6
The Stanley's	Munster	Tipperary	Clay & loam	7.8
John and James Flaherty	Munster	Kerry	Heavy clay	8.2
Wesley Browne	Ulster	Monaghan	Heavy clay	7.9
Glen McCormack	Ulster	Cavan	Heavy clay	7.5
20-farm average				8.2

Grasslands, properly managed, can produce considerable amounts of low-cost and nutritious feed. Grazed grass is the most economical way of feeding cattle under maritime

north Atlantic conditions. It is estimated to cost €70-90/tonne of utilised DM (UDM), which includes a land rental charge along with reseeding, fertiliser, manure spreading and miscellaneous costs (Figure 5). Grass silage, the main winter feed, is about 2.5 times more expensive to produce then grazed grass and is strongly influenced by yield and conservation techniques. Growing maize silage on well-drained loamy soils costs about the same as a tonne of first cut grass silage on a DM basis (Teagasc, 2016). Maize silage and grass silage are usually €120-160 cheaper per tonne DM than purchased concentrate feed compounds, which are the most expensive form of nutrition.

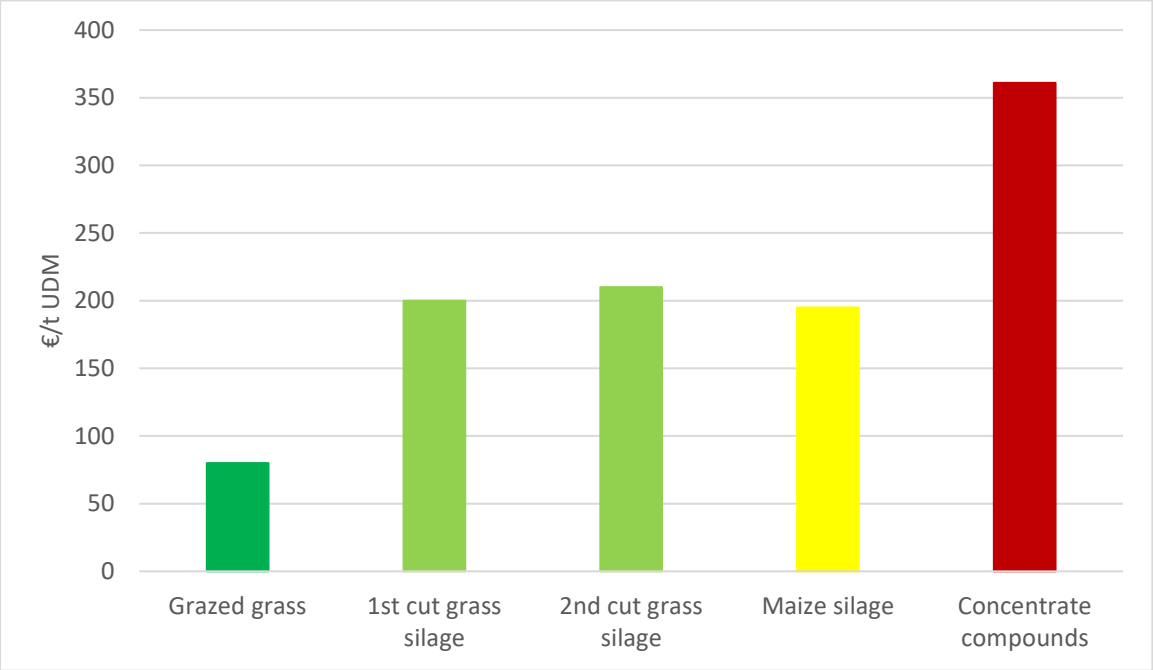

Figure 5. *Relative cost of producing home-grown forages under Irish climatic conditions and estimated price of purchased concentrate feed per tonne of utilised dry matter (UDM). Note: Forage costs include land charge of €400/hectare.*

Concentrate feedstuffs are energy rich supplements regularly offered to cattle in the finishing period to maximise live weight (LW) gain. Late maturing bulls on an unrestricted i.e. ad lib concentrate diet can gain over 1.7 kg LW/day and castrated bulls (steers) are able to put on 1.25-1.45 kg LW/day (Teagasc, 2016). Heifers on this type of diet can gain 1.0 to 1.25 kg LW/day. Target daily LW gains for grass-fed cattle are about 0.3-0.4 kg below animals on ad-lib concentrate feed (Teagasc, 2016). However, the costs and risks associated with rearing and finishing cattle on grass are considerably lower than animals on high-energy diets. The majority of beef farmers therefore attempt to maximise weight gain from grazed grass to make a reasonable income for themselves and their families.

On a typical Irish suckler calf to beef farm, grass constitutes about 90% of the herd's annual feed budget on a DM basis (Teagasc, 2020). As fed, it accounts for over 95% of the feed budget. Grazed pasture is the largest component of the DM diet (60%). Ensiled grass and hay make up 30% of the dry diet and the balance comes from concentrate feed. Beef from cattle on a grass rich diet (i.e. >90% as fed) is widely perceived as healthy, nutritious, animal-friendly and sustainable. This perception is not necessarily based on scientific research even

though several studies support this viewpoint (Herron et al., 2021). The health and sensory benefits of grass-fed beef have started to attract a price premium in certain markets (USDA, 2021). Demand for this form of beef is growing steadily and can be partially satisfied by grass-based Irish beef farms.

4. Value of Irish Beef

Beef production is one of rural Ireland's oldest and largest indigenous industries. The sub-sector produces 580,000-633,000 metric tons of beef carcass every year, and is very much export oriented. Over 90% of Irish beef is sold to 45 countries spread throughout the globe (MII, 2021). This makes Ireland the largest net exporter of boneless beef in Europe and the sixth largest in the world (DAFM, 2020). Great Britain is the primary destination for Irish beef, absorbing about 45% of the sector's exports in value terms. France or the Netherlands is usually the second largest importer of Irish beef followed by Italy, Germany and Sweden.

Table 3. *Value and volume of Irish beef exports (including offal) by destination country, 2018-2020 (Eurostat, 2021).*

	Value (€ million)			Volume ('000 tonne)		
Country	**2020**	**2019**	**2018**	**2020**	**2019**	**2018**
United Kingdom	1,065	1,009	1,206	269	233	235
France	221	247	231	49	55	49
Netherlands	199	200	200	40	44	45
Italy	172	197	184	27	28	24
Germany	151	145	140	18	20	20
Sweden	81	83	87	20	20	19
Belgium	55	55	54	6	6	6
Hong Kong	43	56	63	19	17	17
Spain	42	58	56	10	12	8
Philippines	41	43	32	18	20	19
United States	37	25	10	2	5	8
Switzerland	35	25	25	2	2	4
Denmark	34	44	41	11	12	11
China	24	40	2	1	8	5
Portugal	16	15	16	3	3	3
Japan	16	9	4	1	2	4
Czechia	15	20	16	3	4	3
Canada	13	6	2	1	1	3
Poland	11	11	10	4	4	4
Ghana	10	7	9	9	7	9
All countries	2,302	2,349	2,435	533	527	517

Since 2018, continental Europe's imports of Irish beef (including offal) have been about the same as Great Britain's on a value basis. The continent took approximately 195-215,000 tonnes of the sector's annual exports during this period. Great Britain's share of Irish beef exports typically exceeds Europe's by about 40,000 tonnes/year (Table 3). The rest of the world (ROW) absorbed 67,000-81,000 tonnes of the sector's annual exports between 2018 and 2020. The Philippines and Hong Kong were the largest ROW or third country markets in

terms of volume and value. China and the United States have been among the fastest growing ROW markets in recent years. Together, they took €59 million worth of Irish beef in 2020 versus €12 million in 2018. Total beef exports to the ROW have increased by 45% or €68 million over the same timeframe. Irish beef exports to the ROW are projected to continue growing in parallel with economic development within the region.

The total value of beef exports decreased by 2%, year over year, to €2.3 billion in 2020 and represented 16% of Irish agri-food exports in value terms (Table 4). Food Wise 2025, a 10-year growth strategy for the agri-food sector, projects exports to increase to €19 billion by 2025, creating 23,000 new jobs across the supply chain (DAFM, 2015). Beef is among the agricultural sub-sectors that will drive growth in food exports and employment.

Table 4. *Value of Republic of Ireland agri-food sector exports by category, 2019-2020 (DAFM, 2021b, c).*

	Value (€ million)		
Category	**2019**	**2020**	**Relative change**
Dairy Produce	5,040	5,076	0.7%
Beef	2,349	2,302	-2.0%
Beverages	1,712	1,410	-17.6%
Pig meat	891	886	-0.6%
Fish	578	520	-10.0%
Cereal & Cereal preparation	535	537	0.4%
Live Animals	455	340	-25.3%
Forestry	430	419	-2.6%
Coffee, Tea, Cocoa & Spices	415	421	1.4%
Animal Foodstuffs	367	391	6.5%
Sheep meat	318	354	11.3%
Poultry	294	255	-13.3%
Fruit and Vegetables	159	175	10.1%
Sugar and Honey	152	123	-19.1%
Other[1]	830	937	12.9%
Total	14,525	14,146	-2.6%

[1] Other covers eggs, flax, wool, oilseeds, animal skins and furs miscellaneous products.

5. Processing Sector

Currently, there are approximately 15,000 people directly employed in processing Irish beef (MII, 2021). These jobs are spread between 32 meat processing plants and 132 abattoirs (DAFM, 2021a). Meat exports from Irish processing plants to EU and third-country markets are regulated by the Department of Agriculture, Food and the Marine (DAFM). The slaughter of cattle in abattoirs is supervised by the Local Authority Veterinary Service. Meat processing plants are mainly located in rural areas and are often an important local employer. Workers in meat plants spend their wages in shops and businesses immediately surrounding factories and indirectly create jobs in other segments of the economy e.g., transport, hospitality and professional services.

Four privately owned companies, namely Anglo beef processor (ABP), Dawn Meats, Kepak and Liffey Meats, dominate the Irish beef processing industry. The big four beef processors

own multiple meat plants and operate throughout the country (Figure 6). Three of the big four i.e. ABP, Dawn Meat and Kepak, also have extensive meat operations in the United Kingdom. Information on the approximate share of cattle slaughtered by the big four processors was obtained from the European Commission (2016), the Competition Authority (2021) and industry reports. Anglo beef processor is considered the largest of the big four beef companies in the Republic of Ireland and the biggest beef company in the UK. The multinational processor is expected to increase its share of the Irish cattle market after recently reaching an agreement, in principle, with Fane Valley to takeover Slaney Foods.

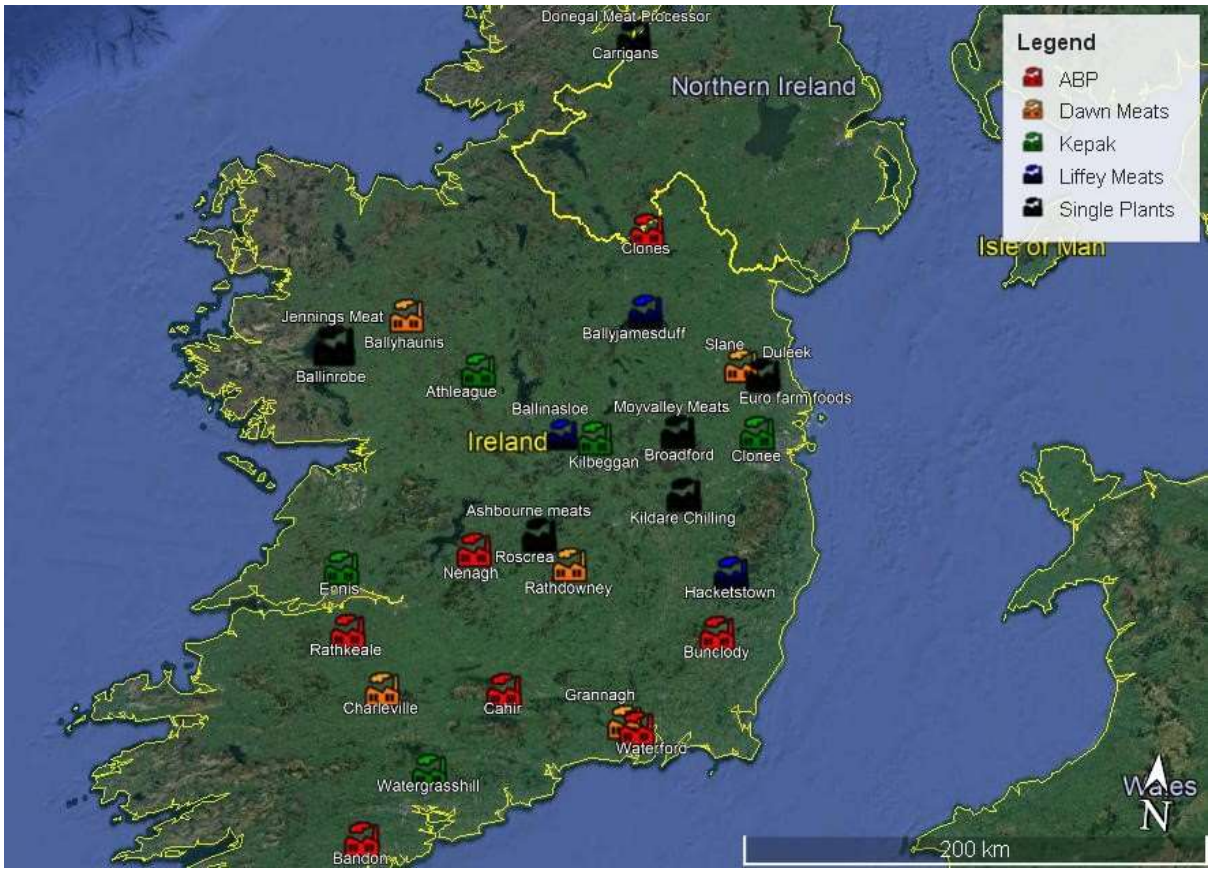

Figure 6. *Major meat processing plants slaughtering beef cattle in the Republic of Ireland between 2018 and 2020.*

Dawn Meats is the second largest beef processor in terms of cattle slaughtered at DAFM approved export plants. The Waterford headquartered company purchased Dunbia's plant in Slane in 2017 and completed a buyout of Dunbia's UK operations in 2020. Kepak has increased its share of the UK market in recent years as well by purchasing 2 Sisters Food group, and ranks ahead of Liffey Meats in the present list of major Irish beef companies. Liffey Meats operates plants in Cavan, Carlow and Roscommon and has a majority stake in a large French meat processor, Chiron Viandes. The family-owned meat company has more than doubled in size in the last twenty year. The growth in Liffey Meats and consolidation in the beef sector, between 2016 and 2019, has increased the big four's share of national cattle slaughterings to approximately 75%. The majority of the remaining balance are slaughtered by six single-plant beef companies (Table 5).

Table 5. *Major Irish beef processors approximate share of national cattle slaughterings at DAFM approved exports plants in 2019.*

Company	Export Plants	Share of cattle throughput (%)
Anglo Beef Processors (incl. Slaney Food)	7	26
Dawn Meats (incl. Dunbia)	5	24
Kepak	5	16
Liffey Meats	3	9
Kildare Chilling	1	5
Moyvalley Meats	1	4
Donegal Meat Processors (Foyle group)	1	4
Ashbourne Meats	1	3
Euro Farm Foods	1	4
Jennings Meats	1	2

Beef companies operating multiple plants regularly feature in the Irish Times (2021) list of top 1000 companies, along with four single-plant processors (Table 6). The largest of these companies, ABP, directly employs 11,000 people and has an estimated turnover of over €3 billion. Dawn Meats is usually next on the list in terms of turnover or revenue followed by Kepak and Liffey Meats. Kildare Chilling is the biggest single-plant processor in terms of employees and turnover. The company's estimated turnover in 2020 was about €23 million greater than Moyvalley Meats. Donegal Meat Processors and Euro Farm Foods employ more staff than Moyvalley Meats, but both had lower estimated revenues than Moyvalley. Euro Farm Foods had the lowest estimated revenue of the top 8 Irish beef companies.

Table 6. Estimated workforce and turnover* of beef processors in Irish Times top 1000 companies, 2020.

Company	Number of Employees	Turnover (€ million)
Anglo Beef Processors (incl. Slaney Food)	11,000	>3,000
Dawn Meats (incl. Dunbia)	7,250	2,100
Kepak	5,000	1500
Liffey Meats	350	150
Kildare Chilling	350	140
Moyvalley Meats	170	117
Donegal Meat Processors (Foyle group)[1]	236	106
Euro Farm Foods[2]	180	86

[1] 2019 estimates. [2] 2018 estimates.

6. Farm Income

Beef farms are relatively small in Ireland and tend to be low-income businesses. In 2020, the average family farm income for cattle rearing operations was slightly above €9,000 and just over €14,800 for finishing systems with some selling of store cattle (Table 7). Average incomes for cattle rearing systems remained unchanged on 2019 levels, while beef finishers income rose by 8%. Family farm income estimates for cattle rearing and finishing were taken from the Teagasc national farm survey (NFS; Donnellan et al. 2021). The purpose of the NFS is to monitor the financial situation on Irish farms. The NFS operates as part of the

EU farm accountancy data network (FADN) and is a nationally representative random sample of 320-350 beef farms. Cattle rearing i.e. suckler calf to weaning or store systems are normally the predominant cattle enterprise in Ireland and the NFS. Other cattle farms primarily represent store or finishing beef systems, which are categorized accordingly within the survey.

Table 7 *Gross output, total costs and income for average beef farming systems in the Teagasc national farm survey, 2019-2020 (€/hectare unless otherwise stated)*

	Cattle Rearing		Cattle Other	
	2019	2020	2019	2020
Gross output	1159	1176	1385	1386
of which direct payments	461	461	491	461
Purchased feed	123	120	206	208
Fertiliser costs	74	72	88	81
Veterinary & breeding	61	68	54	56
Agricultural contractors	95	95	104	100
Other	42	52	53	55
Direct costs	395	408	505	500
Gross margin	764	768	880	886
Car, electricity, phone	76	73	73	70
Buildings and machinery maintenance	105	114	115	121
Land improvement	32	38	37	37
Depreciation	142	120	128	111
Other	124	130	147	144
Overhead costs	479	474	500	483
Total costs	874	882	1005	983
Family farm income	285	293	380	403
Family farm income (€/farm)	9,008	9,037	13,761	14,813

The economic viability of Irish beef farming is reliant on direct payments. Without direct payments, the NFS estimates the net margin for the average cattle rearing system in 2020 was €-5,169 and cattle other enterprises i.e. weanling to store or finish systems averaged a loss of €2,150. Regardless of subsidies and despite higher total costs, the average income for cattle other enterprises was greater than cattle rearing systems. The difference in total costs was largely driven by differences in direct costs rather than overhead costs. Direct costs differed by €92/ha (23%) between the average cattle other and average cattle rearing enterprise, and overhead costs differed by about €9/ha. The divergence in direct costs can largely be explained by greater feeding of concentrate supplements in the cattle other system. Feed purchases and forage production are the main direct costs on beef farms. Feed related expenses (fertilizer, contractor charges, purchased feed) made up 71% of variable cost in cattle rearing enterprises and over 75% of variable costs in other cattle systems. The extra feed purchased in the cattle other system enabled the enterprise to carry more cattle/ha, on average, which led to a greater gross output. The extra output outweighed the extra cost and hence led to a better family farm income for the other cattle system.

In the initial years of LIFE BEEF CARBON, innovative Irish beef farms performed similarly to national average cattle systems in terms of production costs and incomes. The principal financial goals of these farms were:

1) Reduce winter feed costs by utilizing more pasture.
2) Retain 100% of the farm's direct payment.
3) Increase gross output and gross margin.

Over the course of the 4-year project, farm-gate beef LW prices fell by an average of 12% to €1.95/kg (Figure 7). Despite the drop in price, the average gross output of the innovative beef farms rose by €443/ha to €1,662/ha. The majority of the growth in gross output came from increases in the sale of prime cattle. Increases in stocking rate explained the majority of the growth in beef LW sales, about 60%. Improvements in animal productivity accounted for the bulk of the rest of the rise in gross output.

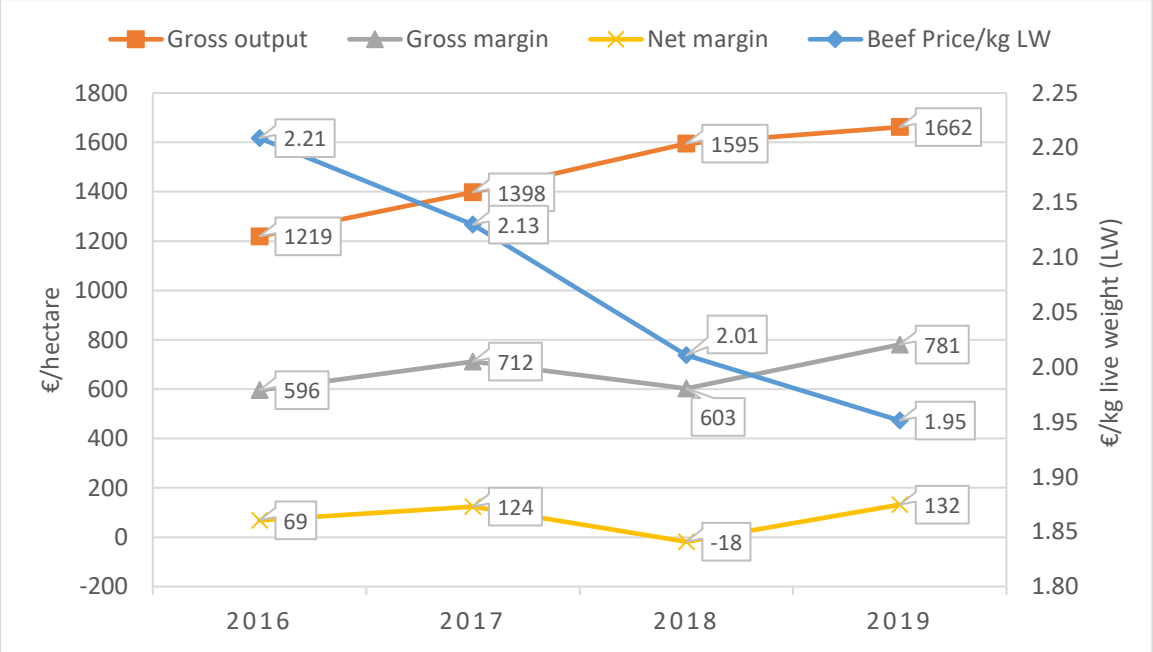

Figure 7. *Gross output, beef price and profitability of the average innovative Irish farm in LIFE BEEF CARBON, 2016-2019. Note: Economic analysis excluded direct payments (subsidies).*

With regard to costs, there were increases in direct and overhead expenses on most farms between 2016 and 2019. Average direct costs went up by €258/ha to €881/ha, and overhead costs rose by an average of €122/ha to €649/ha. Pushing up stocking rates and improving animal performance caused most of the rise in total costs, particularly feed-related expenses. These costs peaked in 2018, due to a severe drought in the main part of the growing season. It was the worst drought in 41 years. The effects of the drought were also felt in the following year, as poor harvests in 2018 pushed up feed prices in the subsequent winter period. Feed costs began to normalise in the spring of 2019 when cattle were left out to pasture after grass growth had resumed.

The sharp rise in costs in 2018 reduced the growth in gross margin on most of the innovative farms and caused net margin to decline by an average of €87/ha, to €-18/ha. Farm incomes recovered in 2019, despite above average direct and overhead costs. The improvement in income was largely driven by increases in the volume of beef sold. Between 2016 and 2019, beef LW sales increased by 300 kg/ha to 852 kg/ha and average gross margin increased by 31% to €781/ha. Net margin rose by slightly more than €60/ha, on average. Without the drop in beef price, net margin would have averaged €327/ha in the fourth year of the project and the average gross margin would have almost reached €1,000/ha (Figure 8).

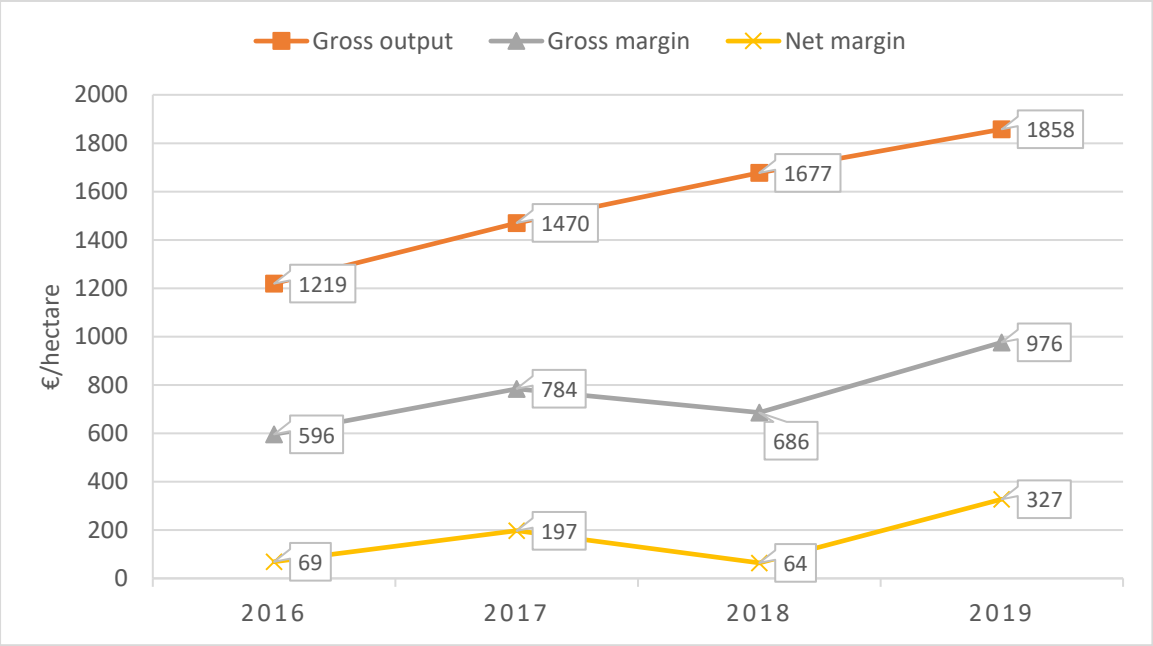

Figure 8. *Gross output and profitability of the average innovative Irish beef farm at a constant beef price, 2016-2019. Note: Economic analysis excluded direct payments (subsidies). Farm-gate beef prices held at 2016 levels.*

Within each year, gross output and profitability varied markedly among some of the innovative beef farms. In 2016, gross output ranged from less than €800/ha on innovative farms operating weanling systems to more than €1,850/ha on farms running store and finishing operations. The range in gross output fell below €1,000 (Figure 9) in the second year of the project, before rising above €1,500 in 2018. Extreme weather in year 3 explained most of the rise in variability. The drought had a negative impact on the gross output of farms on free-draining soil, but it tended to improve the output of some farms on poorly draining soils. Weather had a similar influence on farm profitability. The top 25%, in terms of gross margin, earned €841-1,116/ha in 2018 and the bottom 25% earned less than €370/ha. The gap in gross margin between the top and bottom quartiles decreased by 27% to €345/ha when weather conditions return to normal in 2019.

Net margin varied by a similar degree throughout most of the project and tended to increase on the majority (70%) of farms. The top 25% improved this metric by an

average of €188/ha to €424/ha and the second best group improved by €88/ha, on average. For the bottom 25%, net margin/ha averaged €-264 in 2019, a €42 decrease compared to the base year. Many factors contributed to the deterioration in the group's profitability, including greater investment in new farm practices and technologies. The return from these investments did not fully justify the extra costs the bottom group incurred, but the farms expect the new practices, ceteris paribus, will pay their way in the coming years.

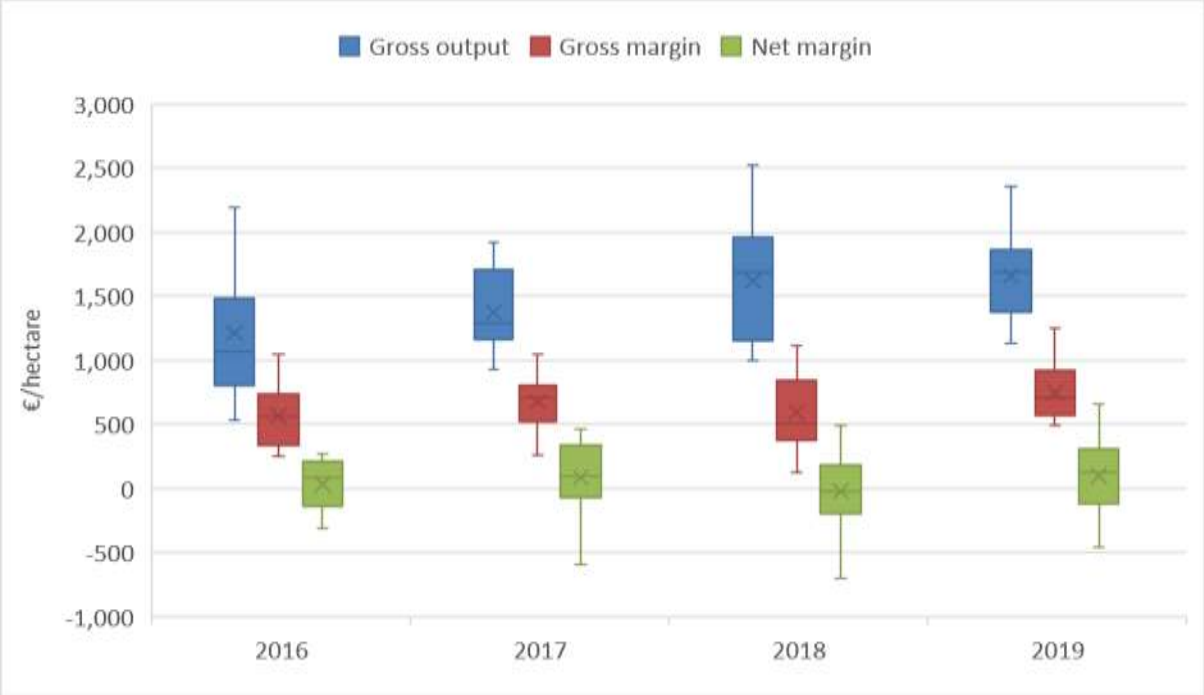

Figure 9. *Box plot of variation in financial performance of the innovative Irish beef farms, 2016-2019.*

7. Carbon Mitigation Costs

Innovative Irish beef farms implemented a range of actions to mitigate the carbon footprint of cattle production such as extended grazing and low emission slurry spreading. These actions were selected from pilot carbon plans developed in the first phase of LIFE BEEF CARBON. The carbon mitigation actions in the pilot plans were categorised into three broad strategies:

1) Improve technical efficiency and performance.

2) Adopt recognised low emission technology.

3) Enhance carbon capture i.e. sequestration in soil and/or vegetation.

The first strategy was the most popular for reducing the carbon footprint of agricultural products. Better technical performance tends to mitigate carbon emissions without compromising beef production and usually has a positive influence on economic performance. Several actions or practices can be applied simultaneously to improve the technical efficiency of a cattle farm. The actions innovative farmers applied to improve technical efficiency depended on their initial i.e. baseline

performance and to some extent on the type of beef farm they operated e.g., actions to improve cow fertility were limited to cattle rearing systems. Generally, the efficiency actions that had the largest positive influence on the carbon footprint of beef LW were:

- Improving calving rate to 0.95-1.02 calves/cow per year.
- Increasing the percentage of maiden heifers calving between 22 and 26 months of age.
- Correcting deficiencies in soil nutrients and reducing soil acidity or alkalinity to the optimum pH level i.e. 6.3 for mineral soils.
- Growing and utilising an extra 1-2 tonnes of grass DM/ha.
- Reducing age at slaughter via genetic gains in lifetime daily live weight gain.

All of the actions the innovative farmers applied to improve efficiency had negative mitigation costs i.e. reduced carbon footprint and production costs (Table 8). Of these actions, growing and utilising more grass had the lowest carbon mitigation cost (€-376 to -485/t CO_2 equivalent), followed by earlier calving in spring (€-198 to -201/t CO_2 equivalent). Calving rate had a carbon mitigation cost of about €-175/t CO_2 equivalent, a little less than reducing the delay in age at first calving. Both of these mitigation actions were responsible for the largest savings in carbon emissions per kilo of beef LW.

Table 8 *Efficiency carbon actions applied on the innovative farms between 2016 and 2019 with related carbon savings in kg CO_2 equivalents/kg beef live weight and mitigation costs in €/tonne of CO_2 equivalent (CO_2e).*

Carbon Action	Metric	Average Change	Carbon saving (kg CO_2e/kg LW)	Mitigation cost
Age at first calving	Days	-97	0.24	-137 to -162
Calving rate	Calves/cow/year	+0.03	0.29	-170 to -178
Slaughtering age	Days	-29	0.22	-184 to -195
Extended grazing – Suckler cows and weanlings	Days at grass	+4	0.07	-126 to -143
Extended grazing – Yearlings (1-2 years)	Days at grass	-3	-0.06	-66 to -80
Grass utilisation	tonnes DM/ha	+0.6	0.10	-376 to -485
Mean calving date (Spring)	Days	-8	0.08	-198 to -201
Soil fertility	P index 3 or 4	+32%	0.05	-44 to -105

Age at first calving fell by an average of 97 days across the farms. Better nutrition and reproductive management were the main drivers behind the improvement in age at first calving. Slaughtering age declined by about a month and was a very cost-effective

action, having a mitigation cost less than €-180/t CO_2 equivalent. The drop in days to slaughter was primarily caused by a 55-gram increase in lifetime daily weight gain. The faster growth rate excludes the weight gain benefits of other actions. It was driven by improvements in forage quality and genetic merit. The rest of the actions implemented to increase farm performance tended to mitigate carbon footprint by 0.05-0.10 kg CO_2 equivalent/kg beef LW, except extended grazing for yearlings (1-2 year old). This action also ranked the lowest in terms of cost effectiveness, notwithstanding its negative carbon mitigation cost. Grazing season decreased slightly for yearlings as some farmers moved towards finishing male cattle at a younger age indoors. Reducing days to slaughter more than compensated for the increase in carbon footprint and costs caused by earlier housing of yearling cattle.

Most of the actions designed to increase farm efficiency could be applied together on the innovative farms and many were additive. Carbon savings from individual efficiency actions were relatively small, typically less than 2% of carbon footprint. However, combining these actions, particularly those focused on grassland and animal productivity, often led to considerable improvements in beef carbon footprint (-10% to -15%). Furthermore, synergistic relationships among efficiency actions increased profitability and reduced financial expenditure by 15-19 cent/kg beef LW. Upscaling this improvement to a national level would increase the sector's financial performance by about €101 million and save over 578,000 tonnes of CO_2 equivalent/year at current beef output levels. Additional savings in carbon could be achieved by combining efficiency improvements with recognized low emission technologies e.g., sexed semen, biodiesel and protected urea (i.e. urea coated with a urease inhibitor).

Currently, the technology with the greatest potential to reduce carbon emissions from Irish agriculture is protected urea. Replacing calcium ammonium nitrate (nitrate) with this straight fertiliser N product has the capacity to reduce the beef carbon footprint of the innovative farms by another 4-5% at little or no cost (€-15/t CO_2 equivalent). Similar reductions are possible at a national scale (Lanigan and Donnellan, 2018). Presently, the carbon mitigation potential of other proven technologies such as trailing shoe slurry spreaders is considerably less than protected urea, and most are cost prohibitive without government funding. Financial supports are available for a small number of these low emission technologies in targeted agricultural modernisation schemes and capital investment schemes. Further financial assistance is likely to be required for more of these technologies and carbon sequestration actions if Irish and European ambitions to become net-zero carbon economies by 2050 are to be realised.

Enhancing soil fertility and better management of grassland were the main actions applied on the innovative farms to increase carbon sequestration. Both actions are among the most effective agricultural measures to remove carbon from the atmosphere and tend to have a positive impact on physical performance metrics, but can require significant investment in farm assets. Carbon sequestration is a long-term

investment. The process occurs over many decades and requires careful management as it is reversible. Investing in carbon sequestration has been estimated to have substantial benefits for the climate and landowners. However, it could not be accurately quantified by the farm carbon-auditing tool used in Ireland. This was in part due to the short timeframe of the project and because of a lack of Irish research on carbon sequestration in grasslands under different management conditions. The latter issue is being addressed as part of the national agricultural soil carbon observatory (NASCO) established in 2021. The new observatory is using eddy co-variance towers to monitor the impact of management on carbon uptake and release from grasslands. Outputs from the towers in NASCO will potentially be used to refine the carbon sequestration module of the farm carbon-auditing tool. The updated tool may be reapplied to calculate sequestration rates on the innovative farms and will be used in future carbon farming initiatives to monitor, report and verify carbon removals. Verified emission reductions or removals could generate new income streams for farmers in the form of carbon credits and thereby improve the economic viability of beef farming in Ireland and elsewhere.

8. Conclusions

LIFE BEEF CARBON demonstrated that the goals of increasing farm profitability and mitigating carbon emissions are not mutually exclusive. Cattle producers can simultaneously improve both sustainability indicators by becoming more technically efficient i.e. use less inputs for the same level of beef production. Irish beef farmers should be able to increase the efficiency of their operations by improving genetics, calving rate, age at first calving, slaughtering age and/or grass utilisation. Combining these improvements has the potential to mitigate the carbon footprint of Irish beef by 10% to 15%, based on the performance of the innovative farms in this project. Becoming more technically efficient has economic benefits as well, but does carry financial risk. Carbon actions focusing on efficiency are generally practical to apply on cattle farms and are “easy wins”. Advances in technology can complement the mitigation potential of efficiency based carbon actions, but these innovations are more costly to implement on farm. Currently, the only low cost technology available to Irish farmers is protected urea. Financial supports are provided for certain low emission technologies specified in modernisation schemes e.g., trailing shoe slurry applicators. Additional grants and supports will be required for more of these technologies if Ireland is to become a carbon neutral economy by 2050.

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