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Food Loss and Waste from Farming, Fishing and Aquaculture in Ireland

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Rialtas na hÉireann
Government of Ireland

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EPA RESEARCH PROGRAMME 2021–2030

Food Loss and Waste from Farming, Fishing and Aquaculture in Ireland

(2019-RE-DS-15)

EPA Research Report

Prepared for the Environmental Protection Agency

by

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This report is based on research carried out/data from 31 March 2020 to 30 March 2021. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The aim of the Efficient Food project was to understand the nature and extent of food loss and waste (FLW) from primary production in Ireland, which includes all FLW occurring in agriculture, aquaculture and fisheries. This study was the first of its kind in Ireland, looking to create a starting point from which FLW can begin to be understood and mitigated. The results will contribute to the food waste statistics reporting required by the European Commission in June 2022, which will be based on 2020 data. The total annual FLW arising from primary production in Ireland was found to amount to 189,485 tonnes. This value was determined through interviews with numerous stakeholders involved in primary production, such as representatives from Teagasc, the Irish Farmers' Association (IFA), Bord Iascaigh Mhara (BIM), the Department of Agriculture, Food and the Marine (DAFM), the Marine Institute, Inland Fisheries Ireland (IFI) and the Sea-Fisheries Protection Authority (SFPA), as well as several commercial producers including farmers, fishers and growers. An in-depth FLW database (Chapter 3) was created and includes detailed reasons for each category of FLW identified for each food type. Most FLW occurs in the vegetable sector, with the average percentage of FLW as high as 40% for some crops. A breakdown of the annual FLW in each food sector (in tonnes) is shown in Table ES1. No major data gaps were identified in the project.

Table ES1. Food loss and waste (tonnes/annum) by food sector, 2020

Food sector	Loss + waste
Meat	41,726
Milk, eggs and honey	4185
Potatoes	72,838
Other vegetables	49,557
Fruit	3803
Grains and legumes	12,502
Fishing	174
Aquaculture	4698
Total	**189,483**

This report describes a number of solutions that can be adopted by producers and other actors in food value chains to strengthen producer capability to reduce FLW (Chapter 4), leveraging the natural, physical, social, human and financial capital within value chains to achieve private and public benefits. Three complementary food governance strategies have been developed as policy recommendations (Chapter 6):

1. Embed low-FLW practices in standard production practice.
2. Implement sustainable intensification of food production activities.
3. Disrupt food production dynamics across food value chains.

The first recommendation requires that all producers be provided with knowledge of efficient, low-FLW practices. The second recommendation entails integrating biological practices and "smart" technologies in production operations. The third recommendation focuses on providing strategies to enhance the decision-making capacity of producers, such as eliminating unfair trading practices, shortening food supply chains and promoting resource-sharing between producers, including sharing of social and knowledge-based resources, for example by strengthening organisational capacity through trading cooperatives and promoting knowledge exchange through producer discussion groups.

1 Introduction

Food loss and waste (FLW) has been examined from multiple perspectives in recent years, through focused disciplinary and multidisciplinary lenses, and by applying different perspectives, for example life cycle assessment, systems approaches, waste hierarchy, circular economy and the water–energy–food–climate nexus, to understand the incidence, drivers and impacts of FLW (Laso *et al*., 2018; Stangherlin and de Barcellos, 2018). The international dimension of this research is indicative of the global nature of the FLW issue, even though local factors, including the prevalent type of production activities, shape both the contours of FLW on regional and national scales and strategies to reduce FLW (Muriana, 2017). The drivers of FLW also vary in their strength along the value chain, resulting in the need for multiple strategies to effectively address those drivers at appropriate stages of the value chain (Muriana, 2017; Stangherlin and de Barcellos, 2018). There is a strong business case for reducing FLW: in a 17-country study of business initiatives to reduce FLW, almost all food waste prevention activities were found to deliver a net positive return (WRAP *et al*., 2020). Moreover, food is a resource that is wasted at immense cost to society. Added to this is the pressure to provide adequate nutrition not only to the current global population, but also to the future population based on population growth projections, creating demand for intensification of agricultural production and fishing efforts. The United Nations reported that 820 million people experienced food insecurity in 2019 (FAO *et al*., 2019), while it is projected that the global population will grow from the current 7.7 billion to 9.7 billion people by 2050 (United Nations, 2019). Without changes to food production systems at global, regional and local levels, the demand for increasing productivity in agriculture and fisheries will exacerbate the substantial environmental and social impacts of food production, contributing to further environmental degradation and challenges to human health and wellbeing (UNEP, 2019).

Clearly, it is crucial to address FLW in order to (1) tackle issues such as inequitable food distribution and access and (2) mitigate any negative impacts of intensive agriculture and fisheries' production processes on the environment through increased efficiency and utility of these processes. Measures to reduce and mitigate losses are as multifaceted as the causes of loss, and include technological solutions, such as digital technologies and the internet of things, economic incentives, social advocacy, regulation, reconfiguration of value chain relationships and holistic, adaptable approaches "that model the non-stationary and holistic behaviour of the phenomenon" (Muriana, 2017), harnessing research expertise and novel technologies (Muriana, 2017; Fitzpatrick *et al*., 2018). Some strategies can reduce FLW but may contribute to long-term challenges for agriculture and fisheries, e.g. reliance on chemical pesticides and fungicides leading to resistance among target pests, or emphasis on high-yielding livestock breeds, shellfish, and seed and crop varieties that may have low disease resistance and tolerance of local environmental conditions.

Fortunately, medium- to long-term strategies to address FLW at the primary production stage of food value chains build on techniques that have been increasingly adopted over the past decade, such as crop production using "minimum-till" soil protection strategies, integrated pest management and species-specific fishing strategies to reduce bycatch and subsequent discards. These FLW mitigation strategies share techniques with "climate-smart agriculture" strategies to mitigate and adapt to climate change, e.g. improvement of soil organic matter, and "One Health" strategies to protect human, animal and ecosystem health, including targeted antibiotic use and integrated animal health management in aquaculture and livestock production. Despite the diversity of approaches towards sustainable intensification of primary production, the objectives are often synergistic, and it is clear that efforts to address FLW in a way that integrates the social and environmental costs of FLW support can contribute to other aims within the agriculture and fisheries sector, e.g. reducing agriculture-derived greenhouse gas emissions, reducing dependence on chemical pesticides, fungicides and antibiotics to treat diseases, building soil fertility, and fostering resilience to climate change on farms, fish farms and in fisheries.

The United Nation's Sustainable Development Goals (SDGs), to which Ireland is a signatory, define the need to reduce food losses along the food supply chain and halve food waste at the consumer stage by 2030 in SDG 12, target 12.3 (United Nations, 2015). These aims have been incorporated in the European Union (EU) Waste Framework Directive, Article 9.1g (EU, 2018), and the EU Farm to Fork Strategy (EC, 2020a), and have also been included in Ireland's Climate Action Plan (Government of Ireland, 2019) and Waste Action Plan for a Circular Economy (DECC, 2019). To reach these targets, knowledge must be developed about FLW occurrence within food supply chains, following which appropriate action can be taken to address it. The Efficient Food study contributes to the development of this essential knowledge, and its aims were to understand and quantify FLW in the primary production sector in Ireland and to identify FLW mitigation solutions, applying the perspective of the waste hierarchy, i.e. prioritising FLW prevention, followed by minimisation, and so on down the hierarchy. The waste hierarchy, described in the Waste Framework Directive of the EU (EU, 2018), orders waste mitigation methods from most favourable to least favourable, as follows: prevention, reuse (human consumption), reuse (animal feed), reuse (by-products) and recycle (food waste), recycle (nutrient recovery), recovery (energy) and disposal. These principles have been adapted to the context of food waste, resulting in the Food Waste Hierarchy (European Commission Joint Research Centre, 2020) (Figure 1.1).

Disposal, which falls within the linear economy model rather than a circular economy model, represents a loss of resources and is always avoided. Anaerobic digestion can convert food waste to energy, but, as energy has a low value, it is not ideal to divert a high-value resource such as food to energy production. Food for human consumption cannot be recovered, recycled or reused for food owing to spoilage; however, value can be recovered from food production efforts, e.g. by returning nutrients extracted from food by composting back to the land. The ideal solution to avoid FLW would be prevention.

The Efficient Food project generated an up-to-date database on FLW in primary food production in Ireland, which includes all FLW occurring in agriculture, aquaculture and fisheries. The project also evaluated gaps in the current state of knowledge and identified strategies to both address any gaps and reduce FLW, resulting in a road map to reduce supply chain losses. To obtain an in-depth knowledge of the current situation in primary production waste at a national level, initial data were sought from earlier studies, such as ICT-BIOCHAIN (2021), ABC Economy (2021) and AgroCycle (2021), as well as the grey and scientific literature, and databases such as Ireland's

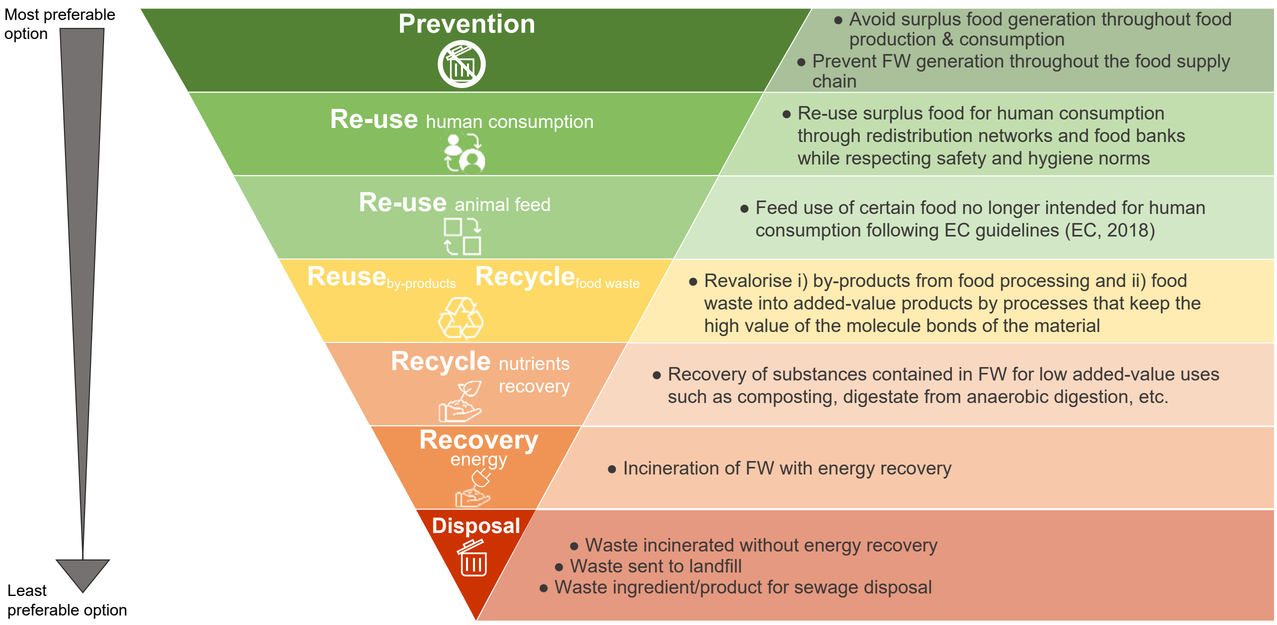

Figure 1.1. Food waste hierarchy (European Commission Joint Research Centre, 2020).

Central Statistics Office (CSO). This information was then supplemented by findings from interviews with industry experts, producers and producer support organisations, e.g. producer associations. The methodology of the study is described in greater detail in Chapter 2.

The study examined land-based and aquatic food production, focusing on animal husbandry, tillage, horticulture, aquaculture and fishing in the marine and near-shore environment, as these are the predominant food production sectors in the land-based and aquatic environments of Ireland. Products that accounted for only a small proportion of total food production were excluded from this analysis, as these losses were considered negligible compared with FLW from the sectors that account for the greatest volumes of food production in Ireland. The results of the investigation of FLW in these food production sectors and the assessment of relevant data gaps are described in Chapter 3.

This study considered a range of strategies to reduce FLW in primary production in Ireland. Emphasis was placed on those solutions that correspond to the sources of FLW identified in Chapter 3, and consideration was given to challenges or trade-offs associated with these identified solutions, which are described in Chapter 4. The conclusions of the study are outlined in Chapter 5. Finally, based on the findings of the evaluation of FLW in primary production in Ireland and the potential solutions available, three major recommendations were identified to address sources of FLW using the identified solutions. These are described in Chapter 6. Medium- and long-term strategies were given priority over short-term strategies, and these largely align with initiatives to ensure that Ireland meets its obligations under SDG 12.3, the Water Framework Directive, the Paris Agreement, the Common Fisheries Policy, the Common Agricultural Policy and the Waste Framework Directive.

2 Methodology

The project was carried out in two parts:

- Part 1: the creation of a database of all the FLW from primary production in Ireland and the identification of data gaps.
- Part 2: the identification of the best solutions to prevent FLW in primary production in Ireland.

The methodologies for parts 1 and 2 are described in sections 2.1 and 2.2, respectively.

2.1 Food Loss and Waste Mapping

A combination of two methods was used to obtain data on all FLW resulting from primary production in Ireland. First, a literature review (of peer-reviewed articles and grey literature) and a review of online databases such as those of CSO, Eurostat and the Food and Agriculture Organization of the United Nations (FAO) were carried out. Subsequently, phone interviews were carried out with numerous stakeholders that included representatives of both national bodies and producer cooperatives, such as Teagasc, the IFA (Irish Farmers' Association), BIM (Bord Iascaigh Mhara) and IFI (Inland Fisheries Ireland), as well as with individual producers, such as farmers, growers and fishers. All the collected data were compiled in a database and the references and contact points for the information were recorded. The food products covered by the project are listed in Table 2.1.

The data were analysed and split into two categories:

1. food loss, i.e. a loss in potential food produced prior to the harvest of crops or animal products, including meat; and
2. food waste, i.e. the loss of harvested food before it can pass into the next stage of the supply chain.

This distinction is defined by the European Commission and has been applied to this research, as Ireland is required to report these data to the Commission from 2022 (EC, 2020b). This categorisation proved subjective at times; for example, it is unclear whether a potato that cannot be harvested because it is too deep for the harvester to reach or too small for it to pick up is to be considered pre harvest (i.e. contributing to food loss) or post harvest (and therefore included in food waste). The project's researchers also doubt their understanding of the definition of food loss, as it would count all animal on-farm deaths as losses, which would result in zero tonnes of waste in the on-farm meat sector each year. The project team therefore recommends that these

Table 2.1. Food products examined by production environment, predominant practice and product category

Production environment	Production sector	Product category	Product types
Land	Animal husbandry	Meat	Beef, pork, poultry, lamb/mutton
		Non-meat animal products	Dairy, eggs, honey
	Tillage	Grains	Barley, rapeseed
		Legumes	Peas
	Horticulture	Vegetables	Potatoes, mushrooms, carrots, parsnips, onions, tomatoes, lettuce, cabbage, broccoli, cauliflower, swedes, Brussels sprouts
		Fruit	Apples, strawberries, raspberries, currants
Aquatic	Fishing (marine/ nearshore)	Shellfish	Abalone, brown crab, clams, mussels, prawns, scallops, squid and octopus, whelk
		Finfish	Angler/monkfish, cod, haddock, hake, herring, horse mackerel, ling, mackerel, megrim, plaice, pollack, Atlantic salmon, coley, whiting, witch flounder, rays
	Aquaculture	Shellfish	Mussels, Pacific oyster
		Finfish	Atlantic salmon

issues are clarified before data are reported to the European Commission.

It is important to note that only products that were intended to be consumed by humans as food were included in the research. This means that culturally inedible food products, such as bones and skin, fish caught for sport or for animal feed, as well as grains grown for energy or animal feed, were excluded, in line with the European Commission definitions of FLW in the Waste Framework Directive (EC, 2020b). In addition, animals that died very young were excluded, as it is common and natural that a proportion of animals die young, both in the wild and when managed through agriculture/aquaculture. This is explained in more detail in section 3.1.

Finally, owing to the timeframe of the project, which was only 12 months, it was neither possible nor intended that FLW from each food sector would be completely studied. Several stakeholders were interviewed and their knowledge and opinions were aggregated to establish the likely national average of FLW for each food type. This, however, means that lesser-known issues within the food production system may have been excluded and bias may be present in the results, among other errors. The project was intended to give an initial picture of FLW in primary production and thus identifies problematic areas that would benefit from the implementation of mitigation actions.

2.2 Recommendations

Producers stand to benefit from reducing FLW, including through increased profits resulting from greater utilisation of the food produced. However, the amount of FLW at the primary production stage suggests that, at the time of writing, the benefits of FLW reduction are exceeded by the costs, including indirect costs, for example the increased labour costs associated with changes to production practices or the acquisition of knowledge and skills as well as the cost of developing alternative market opportunities. Sen (1993) has proposed that choice is determined by the capability of individuals to do and achieve the things they value, rather than by utility or resource trade-offs. Those capabilities are influenced by the inherent characteristics of individuals (e.g. age and biophysical characteristics), the resources that individuals have access to (e.g. financial and material capital), and the social, economic and political environment in which they are situated (Sen, 1985, 1999). For example, in the context of food production, the food value chain constitutes a great deal of the social, economic and political context influencing food producer capabilities. The "capability approach" has been subsequently elaborated and adapted to evaluate a variety of development issues and objectives, including food production (Samerwong *et al.*, 2020). Samerwong *et al.* (2020) identified a number of types of capital that producers can mobilise to strengthen their capabilities, including the capability to efficiently produce high-quality food. Drawing on the sustainable livelihoods approach (Department of International Development, 1999), Samerwong *et al.* (2020) describe these types of capital as human, social, natural, physical and financial. Table 2.2, drawn from the work of Samerwong *et al*. (2020), identifies the assets and capabilities associated with different types of capital and gives practical examples of how those capabilities might be implemented to increase production efficiency in aquaculture.

This review applies the capitals framework described by Samerwong *et al.* (2020) to evaluate the range of institutional, social and material interventions that can build producer capability to address FLW and are applicable to the Irish production context. This includes interventions at other stages in the value chain that may contribute to the reduction of FLW, through the influence of downstream food management practices on producer capabilities to minimise FLW. These FLW solutions are described in Chapter 4 and are presented in terms of the primary type of capital they engage. It is important to note that the greatest benefit for producers and for FLW reduction is derived from the delivery of combinations of these interventions, for example the introduction of new technology that requires financial capital to purchase or build and human and physical capital to operate. Policy recommendations derived from a combination of several interventions are described in Chapter 6.

Table 2.2. Capital, capabilities and examples from aquaculture

Capital	Assets	Capability	Example
Human	Knowledge, personal health, skills, labour, access to education and training	Ability to retrieve information, to understand, to reflect and to physically carry out activities (e.g. to work)	An educated producer is more likely to correctly read drug prescriptions and, therefore, administer the correct drug doses, maximising the chance of having a healthy stock
Social	Social networks and informal relationships, memberships of formalised groups or associations	Ability to collaborate with, and learn from, others, to engage in reciprocal interactions and to forge and maintain informal and formal relations	A producer connected to skilled/educated others (neighbours, co-producers, organisation members) is more likely to ask for help and have broken tools or system errors fixed in a quick and cost-efficient manner
Natural	Natural resources, both living and non-living (geology, land, soil, water, stocks, genetic resources), and/or rights to access natural resources	Ability to situate one's practices in an environment/ecosystem which provides necessary inputs for operations and/or is insensitive (or has low sensitivity) to a farm's waste outputs	A producer whose farm is located in an area with a year-round good-quality water supply is more likely to enable healthy stock growth
Physical	Energy, irrigation and sanitation systems, buildings, transport means and infrastructures, production technologies and equipment	Ability to operate easily, efficiently and effectively or have infrastructures, systems or equipment in place for operating	A producer who has well-designed fish ponds or cages is more likely to avoid escapes
Financial	Money and savings, access to loans, credits, financial services	Ability to purchase goods and services for production, to receive credit or make investments to sustain ongoing and future operations	A financially solvent producer is more likely to be able to make large or long-term investments in improving farm management

Adapted from Samerwong *et al*. (2020); licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

3 Food Loss and Waste Mapping

The FLW mapping was primarily based on interviews with stakeholders, as the literature search revealed that systematically recorded national data are non-existent for most food sectors, except for fish discards and on-farm deaths of beef cattle and pigs. Food loss and food waste for each food sector and in total are quantified in Table 3.1. In Tables 3.2–3.9, each value from Table 3.1 is further broken down into absolute (tonnes/annum) and percentage loss or waste, along with specific and detailed reasons for the loss or waste. The data are categorised as either a "loss" or a "waste" (waste highlighted in grey) as defined by the European Commission and explained in section 2.1. The results are explained in more detail in section 3.1 for animal husbandry, in section 3.2 for tillage and horticulture, and in section 3.3 for fishing and aquaculture. The figures detailed in Tables 3.2–3.9 are estimates obtained from stakeholder interviews or, in the case of fish discards and on-farm deaths of beef cattle and pigs, are taken from animal loss records. When records were available, the proportion of FLW accounted for by animal loss was calculated from the values for animal losses and total production (in tonnes or animal numbers, as appropriate for the available data). When FLW was calculated on the basis of estimates gathered from stakeholder interviews, the values in the tables are based on the proportion of total production (in tonnes or animal numbers, as appropriate for the available data) accounted for by the FLW estimates. In the case of produce for which a proportion of the reported quantities is typically inedible, e.g. skin and bones of fish, or quantities are reported in units of produce rather than by weight, e.g. beef cattle, FLW quantities are based on the edible fraction of the produce concerned, as calculated from figures provided by stakeholders and available in the literature (Ranken and Kill, 1993; Department of Fisheries and Aquaculture for Newfoundland and Labrador, 2003; Pfeiffer and Nautilus Consultants Ireland Ltd, 2003; James *et al.*, 2011).

In addition, each section includes a description of data sources and any data gaps or other issues (such as potential bias or data skewness) encountered during data collection. Individual names and the names of private companies were omitted from the report to both protect the individual's identity and encourage sharing of data. Readers who would like to approach a particular individual directly should get in touch with the project research team in the first instance, who will provide the individual's contact details if granted permission to do so.

3.1 Animal Husbandry

The animal husbandry sector is divided into two subsectors: meat products (Table 3.2) and non-meat products (Table 3.3). The weight of FLW represents the edible parts of the animals only, based on the proportion of edible and inedible (e.g. bones) matter for each species examined.

Relevant systematically collected national data are rare, and are available only for on-farm deaths of

Table 3.1. Summary of annual food losses (i.e. before harvest) and waste (i.e. post harvest) (tonnes/annum) from primary production in Ireland

Food sector	Loss	Waste	Loss + waste
Meat	41,726	0	41,726
Non-meat animal products (milk, eggs, honey)	3285	900	4185
Vegetables (field and protected)	57,384	65,013	122,397
Fruit	1548	2255	3803
Tillage (grains and legumes)	11,372	1130	12,502
Fishing	0	174	174
Aquaculture	3757	941	4698
Total	**119,072**	**70,413**	**189,485**

Table 3.2. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the meat sector

Food	Category	FLW (%)	FLW (t/a)	FLW reason
Beef	6 weeks to 6 months	2.4	2212	Respiratory and gastrointestinal infections
	6 months to 1 year	1.4	2530	Respiratory and gastrointestinal infections
	1–4 years	2.5	9849	Respiratory infections, undiagnosed cases
	>4 years	3.1	15,826	Birthing problems, respiratory infections, undiagnosed cases
Pig	Post weaning	2.9	766	Playing and biting leading to infection, disease including viral pneumonia, meningitis
	Finisher	2.7	6730	Disease including viral pneumonia, meningitis
	Sow	6.7	1146	Birthing problems, disease including viral pneumonia, meningitis
Sheep	Lamb	0.5	82	Pneumonia, if infection occurs before vaccine takes effect
				Predators, accidental, other
		1.0	165	Disease including clostridial, nematodes, iceberg diseases
		0.5	82	Liver fluke
	Ewe	2.0	218	Birthing problems, liver fluke
Turkey	Stags	5.0	289	Heart attacks, hip dislocations, leg injuries, disease including blackhead, coccidiosis
	Hens	3.0	132	Heart attacks, hip dislocations, leg injuries, disease including blackhead, coccidiosis
Chicken	All	2.0	1485	Leg injuries, often due to rapid growth
				Heart attacks, often due to rapid growth
				Diseases (very low levels)
Duck	All	2.3	132	Sudden death with blood splatter in the lungs
				Footpad dermatitis
				Environmental issues including ventilation, temperature, humidity
				Genetic issues that make the birds more prone to illnesses/infections
Total		**4.6**	**41,726**	

Table 3.3. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the non-meat animal products sector

Food	FLW (%)	FLW (t/a)	Reason
Cow's milk	3.0	3285	Mastitis
	Negligible	0	Ill and under treatment (therefore unsuitable for human consumption)
Chicken eggs	2.0	900	Breakages due to issues with the egg belt
			Calcium deficiencies in older hens (increasing due to lengthening of the laying cycle)
Honey	Negligible	0	Lead contamination from storage in aluminium containers
	Negligible	0	Thymol contamination from excessive feeding with fondant
	Negligible	0	Fermentation
Total	**0.05**	**4185**	

Grey shading in tables indicates waste.

pigs and dairy cows and beef cattle [farmers are required to provide these data under Regulation (EC) No. 1165/2008 (EU, 2008)]. In both sectors, however, reasons for deaths are not recorded and, as a result, there have been no studies of the reasons for on-farm deaths in Ireland. The reasons for pig deaths were provided by a member of the IFA National Pig Committee.

In the case of cattle, stakeholders pointed to the animal health surveillance reports (DAFM, 2020a), although these include only those cattle that are taken to the laboratory for post-mortem examination. When there is a cluster of on-farm deaths, the farmer will generally send only one animal to the laboratory, and therefore the number of reported on-farm deaths is highly skewed towards deaths from those diseases that do not spread quickly. Similarly, reasons for death that are obvious and can be determined by the farmer will be under-represented in the reports. In addition, in a proportion of cases, the cause of death remains undetermined. This figure ranges from 3% in neonatal calves to 15% in adult cattle. However, as on-farm deaths are considered to be low overall in Ireland, there does not appear to be a strong need to fill this gap in the data. In the past, when there have been severe health issues in cattle, this has been addressed. The same is true for most other animals in Ireland, i.e. mortality of chicken, sheep, ducks and pigs is low, and undiagnosed causes of mortality are even lower; therefore, the research team deemed it unnecessary to recommend an endeavour to obtain more accurate data through scientific studies.

As mentioned previously, apart from pigs and cattle, no information was available about on-farm animal deaths from scientific studies; therefore, in the case of the remaining animals (sheep, chicken, turkey and duck), the entire dataset was collected through stakeholder interviews. Representatives from Teagasc and Sheep Ireland, both of whom are sheep farmers themselves, provided the sheep data, while information on chickens (broilers) was provided by a Teagasc poultry representative, a member of the IFA Poultry Committee, a representative from a veterinary services company and one of the major chicken producers in Ireland. Deaths of laying hens were excluded from the study, as laying hens are not intended to be consumed for meat in Ireland. In the case of turkeys and ducks, the information was provided by a Teagasc poultry representative as well as by major commercial Irish turkey and duck producers.

It is worth noting that sudden death appears to be common in the poultry sector, and is frequently attributed to farming practices that aim to grow animals at a rate that is faster than their natural growth rate and can result in health issues such as heart attacks. Such fast growth can also cause issues with leg joints and hip dislocations, ultimately leading to low productivity and early death. In the duck sector, stakeholders investigating sudden deaths have discovered that blood splatter in the lungs is a frequent finding but it is, as yet, unknown whether or not this can be avoided. It has been proposed that sudden deaths could be reduced by raising different breeds of poultry. However, the loss in efficiency may result in more lost livestock production resources (i.e. the resources that go into breeding, keeping and growing the animals) and there are few commercial breeds of chicken available globally. In addition, in the case of turkeys, the sector is deemed not large enough to warrant the necessary research. Free-range poultry production techniques may be an option for chickens, as this results in slower growth rates than those achieved with housed poultry production techniques. In any case, the mortality rate for chickens and ducks has been controlled and has fallen in recent years and has now reached a level at which further research about the causes of mortality is no longer necessary, as solutions have been identified, e.g. raising slower-growing poultry breeds.

A final gap in the animal loss and waste data relates to young animals. It is common and natural that a significant proportion of animals die within the first week of life, although this proportion is in decline as a result of the high level of care that farmed animals now receive, as well as continued outbreeding of genetic disorders. This means that, in contrast to deaths of older animals, which can be increased by ventilation issues, a lack of hygiene or close confinement, it might be misrepresentative to consider deaths of young animals as FLW. For this reason, chickens and ducks below 1 week of age were excluded from the calculations in this study, as were cows, pigs, sheep and turkeys younger than 6 weeks of age.

The non-meat animal products studied were milk, eggs and honey. In all three cases, waste was either very low or non-existent. Losses in the milk sector are largely due to mastitis, which is well understood, and efforts are being made to manage it. Milk data were obtained from the IFA milk committee. Egg data were obtained from the Teagasc poultry representative and

Table 3.4. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the field vegetable sector

Food	FLW (%)	FLW (t/a)	Reason
Potato	7.5	34,143	Harvesting losses – too deep or fall out of the harvester
	5	22,762	Not marketable (go for cattle feed)
	3	13,657	Store losses due to moisture losses
	0.5	2276	Diseases including gangrene, pink rot, soft rot, dry rot
	Invisible	0	Potato cyst nematode
Carrot	7.5	4895	Pests and diseases (cavity spot, *Fusarium*, *Sclerotinia*)
	5	3263	Breakages
	5	3263	Deformities (forking and fanging)
	10	6527	Extreme weather (frost, flooding)
Parsnip	15	1302	Canker
	5	434	Mechanical damage
	5	434	Deformities (forking and fanging)
Onion	15	466	Diseases during drying, curing and storage
	10	699	Damaged and outside supermarket specification requirements
	Unknown	0	Change in supermarket specification requirements
Outdoor lettuce	40	1434	Weather conditions resulting in damage or a change in harvesting schedule Pests and diseases Availability of imports in autumn
Cabbage	15	4663	Variable demand and availability
	10	3109	Pests and diseases (mostly in autumn and winter due to weather conditions)
Broccoli	20	1776	Unplanned production due to shifts in weather (e.g. crops harvested earlier due to earlier than expected warm weather or storms)
	5	444	Weather (snow, extreme wind, drought, waterlogging)
	2.5	222	Pests and diseases (in field)
	2.5	222	Pests and diseases (in storage)
	5	444	Supermarkets cancel orders at the last minute
Cauliflower	20	1178	Unplanned production due to shifts in weather
	5	294	Weather (snow, extreme wind, drought, waterlogging)
	2.5	147	Pests and diseases (in field)
	2.5	147	Pests and diseases (in storage)
	5	294	Supermarkets cancel orders at the last minute
Swedes	8	2208	Not meeting customer specifications, misshapen
	6	1656	Pests and diseases (dry rot or *Phoma*, crater spot), nutritional deficiencies (e.g. boron deficiency), weed control; 50% are hand harvested, and unsaleable swedes are left in the field and are classified as pre-harvest losses
	6	1656	Pests and diseases (dry rot or *Phoma*, crater spot), nutritional deficiencies (e.g. boron deficiency), weed control; 50% of swedes are machine harvested and, therefore, waste is post harvest
Brussels sprouts	25	767	Bacterial breakdown due to wet weather at harvesting, pests and diseases, grade-outs
Total	**18.7**	**114,782**	

an industry stakeholder. Honey data were obtained from the Department of Agriculture, Food and the Marine (DAFM), the Federation of Irish Beekeepers and Teagasc.

3.2 Tillage and Horticulture

The tillage and horticulture sector is divided into four subsectors: field vegetables (Table 3.4), protected vegetables (Table 3.5), fruit (Table 3.6) and tillage (Table 3.7).

In the fruit and vegetable sector (both in-field and protected), the reasons for losses and waste were varied but included pests and diseases, extreme weather, lack of crop rotation and good soil management, aesthetic reasons, mechanical damage, unskilled workers, storage issues, changes in demand and the availability of imports. The data were obtained

Table 3.5. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the protected vegetables sector

Food	FLW (%)	FLW (t/a)	Reason
Mushroom	7.5	5659	Supermarkets request stalks cut off for aesthetic reasons
	2	1509	Disease
	Unknown	0	Poor-quality mushrooms
Tomato	4	165	Unsaleable fruit (damaged, overripe) Unskilled workers (not noticing pests or not harvesting properly) Supermarket returns due to quality issues
	1	41	Pests and diseases
Indoor lettuce	5	240	Change in consumer demand, e.g. due to a wintry summer week Pests and diseases
Total	**9.0**	**7614**	

Table 3.6. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the fruit sector

Food	FLW (%)	FLW (t/a)	Reason
Apples (fresh)	15	2255	Storage rot and disease
Apples (processing)	0.6	42	Pre-harvest rot/disease
Strawberries	11.7	794	Disease (particularly mould and mildew)[a]
	10	599	Small or unripe fruit
	1.5	91	Insects
	Negligible	0	Storage rot and decay
Currants	5	8	Fallen fruit
Raspberries	2	7	Disease
	2	7	Insects
	Negligible	0	Storage rot and decay
Total	**12.6**	**3803**	

[a]Severity varies depending on weather conditions. The FLW (%) is based on range of losses, from 5% (typical with suitable weather conditions) to 50% (hot weather/heatwave conditions, typically once every 7–8 years).

Table 3.7. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the tillage sector

Food	FLW (%)	FLW (t/a)	Reason
Spring barley for brewing/stilling/malting	5	5610	Necking or brackling (yield too high)
	4	4488	Fallen crops from poorly applied nitrogen-containing fertiliser (machine setting errors)
	1	1122	Respiration
	Negligible	0	Combine harvester flaws
Winter barley for brewing/stilling/malting	1.5	1189	Necking or brackling (yield too high)
	Negligible	0	Combine harvester flaws
Spring rapeseed for cooking oil	5	26	Shelling before harvest
	1	5	Respiration
	Invisible	0	Rotation period is too short (therefore less productive)
Winter rapeseed for cooking oil	1	3	Respiration
	2.5	6	Shelling before harvest
	Invisible	0	Rotation is too narrow (therefore less productive)
Peas for food	4	53	Strength of rain destroys the plants
	Invisible	0	Rotation is too narrow (therefore less productive)
Total	**6.5**	**12,502**	

entirely from interviews with experts at Teagasc, the IFA Horticulture Committee, the Horticulture Industry Forum and the Irish Apple Growers' Association and with eight of the larger commercial growers in Ireland. The estimations varied only slightly, if at all, between experts and growers, suggesting that the figures provided are accurate. The fruit and vegetables studied were those with the largest annual production.

Reasons for losses and waste fall into two main categories: those attributable to retailers and those related to farming practices. Retailers are responsible for the majority of FLW, as they decide what to sell, and this is based on their most successful marketing techniques, such as weekly offers, rather than on what vegetables are in season and available or in abundance at the time. Losses and waste attributable to retailers' practices are easily quantified. Reasons for major losses falling into the second category can be solved by farmers themselves by using more holistic farming methods but are less quantifiable. Various complex factors (such as weather) determine whether or not a plant might grow to the required standard. This means that it is difficult to associate specific reasons with a certain quantity of loss or waste. Rather, there are multiple reasons, and these are, for the most part, a result of a lack of holistic farming approaches in Ireland such as avoiding monocultures, rotating crops, using natural methods of biological pest control, avoiding overcultivation, using mixed farming systems and increasing the focus on soil health. The exact quantity of current losses and waste that could be avoided by the adoption of holistic farming practices has yet to be determined but, given the volumes of FLW occurring in this sector, an in-depth review of the potential solutions, including the project team's recommendations for those best suited to the Irish production context, has formed a strong part of the recommendations in Chapters 4 and 6, respectively.

Most tillage produce farmed in Ireland is not intended for human consumption. This means that, although losses may be significant (because the sector is very large and crop rotation is rare), the fraction lost from the food chain is minimal compared with the size of the sector. We also completely excluded from the study crops that are grown mainly for purposes other than human consumption, such as oats and wheat. The size of these losses and reasons for these losses are all based on expert estimates. The reasons are well understood and therefore there are no data gaps in the sector. The data for this sector were obtained from a number of Teagasc experts and the Crops 2030 report (Teagasc, 2020a).

3.3 Fishing and Aquaculture

The fishing and aquaculture sector is divided into two subsectors: fishing (Table 3.8) and aquaculture (Table 3.9). FLW takes into consideration only the edible parts of the fish, based on the proportion of edible and inedible matter for each species examined.

The marine sector shows differences from the other food sectors in that a number of national committees or research organisations, each with different core mandates, engage with primary producers in this sector. For example, the Sea-Fisheries Protection Authority (SFPA) and IFI are primarily concerned with fish conservation and the Marine Institute with research while BIM provides support for the fish industry, although all of the organisations engage with all objectives to some extent. It was apparent during interviews that there was less agreement among these organisations than among organisations engaged with other sectors. Interviewees were also keen to avoid the labels "loss" or "waste", preferring terms highlighting the potential uses of fish and fish parts not entering the food chain, such as "co-product". Interviews were conducted with representatives from the SFPA, the IFI, the Marine Institute, BIM and from fishers and fishing cooperatives. The interviewees from the fishers and fishing cooperatives provided information on crab, pelagic, whitefish, *Nephrops* and freshwater fisheries, while BIM, the Marine Institute, the SFPA and the IFI provided information about those fisheries, including records of losses, and other fisheries with less substantial catches or

Table 3.8. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the fishing sector

Food	FLW (%)	FLW (t/a)	Reason
Brown crab	Negligible	0.5	Whole: quality-related losses, discarding
	11.5	127	Clawed: de-clawing and discarding of body meat/use as bait
Dublin Bay prawn (*Nephrops*)	Negligible	0	Quality-related losses
	0.2	4.1	Discarding
Mussels	20	21.6	Quality standards including fouling, shell breakages, undersized
Scallops	Negligible	0	Quality-related losses
Squid/octopus	Negligible	0.7	Quality-related losses, discarding
Whelk	Negligible	0	Quality-related losses, discarding
Angler/monkfish	Negligible	0	Quality-related losses, discarding
Cod	Negligible	0	Quality-related losses, discarding
Haddock	Negligible	0	Quality-related losses
	0.3	5.7	Discarding
Hake	Negligible	0	Quality-related losses
	Negligible	2.9	Discarding
Herring	Negligible	0	Quality-related losses
Horse mackerel	Negligible.	0	Quality-related losses, discarding
Ling	Negligible.	0	Quality-related losses, discarding
Mackerel	Negligible	0.1	Quality-related losses, discarding
Megrim	Negligible	1.1	Quality-related losses, discarding
Sprat	0	0	Quality-related losses
Whiting	Negligible	0	Quality-related losses
	0.3	3.9	Discarding
Witch flounder	Negligible	0.1	Quality-related losses, discarding
Rays	Negligible	0	Quality-related losses
	1.1	6.5	Discarding
Total	**0.3**	**174**	

Table 3.9. FLW percentages, annual quantities (tonnes/annum, t/a) and associated reasons in the aquaculture sector

Food	FLW (%)	FLW (t/a)	Reason
Salmon	2	23.5	Filleting
	0.007	0.6	Escapees
	20	2037	Disease/infection/illness including gill disease, pancreatic disease, algal blooms and endoparasites, exacerbated by jellyfish, sea lice, environmental conditions[a]
Mussels	Negligible	0	Shipping (export)
	20	322	Quality standards (grading/packing), e.g. fouling, shell breakages, undersized mussels
	Negligible	0	Quality-related losses
Pacific oyster	15	595	Handling and grading (adults)
	7.5	274	Disease, environmental stress
	30	1446	Handling and grading (juveniles)
	Negligible	0	Suboptimal hatchery practices leading to "doubles" or to seed oysters that are more vulnerable to pathogens and environmental stresses
	Negligible	0	Shipping (export)
Total	**50**	**4698**	

[a]High temperature and low water movement/stormy conditions can lead to skin damage, leaving fish vulnerable to bacterial infections.

involving few fishers, e.g. wild mussels and native oysters. The fact that a wide variety of organisations and fishers engaged in the study helped to minimise discrepancies in the information provided by interviewees due to differences in perspectives and knowledge, and any discrepancies resulting from disagreement between stakeholders in the sector or omission of information due to a lack of trust between stakeholders. If these stakeholders are to collaborate in the reduction of FLW, it would be appropriate to improve communication among fishers, fisheries organisations and policymakers and to involve fishers in decision-making.

Fishing sector waste was mostly attributed to discarding. Discard rates vary across fisheries, and in some cases discarded fish are not considered waste, as fish have a high survival rate when returned to the sea (James *et al*., 2011). The Landing Obligation, or "discards ban", which requires all fish caught to be landed and recorded, was introduced as part of the 2013 EU Common Fisheries Policy (Cosgrove *et al*., 2015). The Landing Obligation was phased in gradually from 2015 until 2019, when it came into full effect for all species managed under the total allowable catch and quota system (SFPA, 2016). Fish can still be discarded at sea in exceptional circumstances (exemptions to the Landing Obligation). This study considered discarding only of those species that are typically consumed as food.

The main source of food waste due to discarding is the de-clawing of brown crabs and subsequent discarding of crab body meat. In Ireland, owing to the seasonal variation in body meat quantity and quality, and the low demand for whole crab compared with crab claws (Garrett *et al*., 2015), most crabs are landed and both claws are removed, either ashore or in the harbour (Pfeiffer and Nautilus Consultants Ireland Ltd, 2003; Fahy *et al*., 2004; Garrett *et al*., 2015). A portion of the de-clawed crabs are sold to whelk fisheries as bait, while the remainder is discarded in harbours. The survivability of discarded de-clawed crab is low because their feeding capacity is impaired and they are susceptible to disease as a result of claw removal and time spent out of water (Pfeiffer and Nautilus Consultants Ireland Ltd, 2003; Fahy *et al*., 2004; Patterson *et al*., 2009).

The discarding at sea of whole fish also contributes to fishing sector waste. In the case of fish species that are typically consumed as food, permitted reasons for discarding include fishers exceeding their quota for non-target, "choke" species, thereby preventing further fishing for target species (de minimis exemption); and the accidental catching of fish that cannot be sold (by-catch) for either quality reasons, e.g. predator damage, or conservation reasons, e.g. fish below minimum conservation reference size, regional fisheries management obligations or a combination of these. The extent of fish discarding continues to be studied by BIM, the SFPA and the Marine Institute. The work has confirmed that the Landing Obligation has been successful in mitigating discarding, and further measures are being developed to reduce discards without compromising fishery viability, e.g. discarding of non-target species.

Another unquantifiable reason for loss in this sector is pollution and environmental change. Some areas that were previously fished are no longer habitable for fish, while pollution also causes fish deaths (IFI, 2017). Losses in this category are excluded from the database not only because they are unquantifiable but also because the fish in question have not yet entered the food chain. Whether or not they have entered the food chain is a matter of debate; the fish are wild and not in any food chain-related process, but their loss directly affects the food chain. Pollution and environmental changes, e.g. anthropogenic climate change, have resulted in fewer fish being available to catch and, as a result of decreasing fish populations, the fishing quotas for these fish have also been reduced.

In the aquaculture sector, a limited number of species accounted for the majority of produce: mussels, Pacific oysters and Atlantic salmon. The producers of these species are represented by a more limited number of national bodies than producers in the fishing sector, but relationships between national aquaculture bodies and fish farmers are strong. Interviewees included producers, members of the IFA Aquaculture Committee and staff of BIM, each with a national-level overview of production conditions and who engaged their mussel and oyster farmer network to investigate and validate loss estimates on behalf of the researchers. In addition to national coverage of mussel and oyster farmers, the interviewees accounted for 66% of Irish Atlantic salmon production, and included mussel farmers in regions experiencing extreme production challenges.

As in the marine sector, there are gaps in our knowledge of the extent to which pollution and environmental changes, including the effects of climate change, such as increasing sea temperature and the increased intensity of storm and rainfall events, contribute to aquaculture losses. However, although the extent to which these factors cause losses is unknown, they are considered to exacerbate physiochemical causes of salmon, mussel and oyster mortality, such as sudden declines in salinity following rainfall, excessively warm sea temperatures, stormy seas and a severe decline in the suitability of seed mussel habitat. Similarly, pollution and anthropogenic environmental changes exacerbate biological causes of salmon, mussel and oyster mortality, as well as production challenges such as the incidence and impacts of pathogens, pests and predators (e.g. jellyfish attacks on salmon).

Research is ongoing in Ireland and internationally to understand the contribution of these factors to impaired growth and death among salmon, mussels and oysters, and how to mitigate those losses, e.g. through vaccine development and changes in production infrastructure. Owing to gaps in knowledge about the significance of these factors for the main types of aquaculture in Ireland, losses associated with production practices that induce stress in oyster production, such as handling and grading, are challenging to disaggregate entirely from losses associated with environmental stresses, including pathogens, and it is possible that losses attributed to oyster handling and grading practices are inflated by the contribution of environmental stress. Repeated consultation with BIM, and between BIM and its oyster farmer network, was undertaken to establish the specific contribution of handling and grading practices as far as possible; however, without further research in this specific field it is not possible to establish further clarity on this issue.

4 Solutions

The tables in this chapter describe interventions to strengthen producer capability to address FLW. Initiatives aimed at diverting FLW, for instance to alternative, non-food, markets (animal feed, inputs for bio-based ingredients, materials, pharmaceuticals, etc.), were identified in the research process but are not included in this report. Such initiatives are lower on the food waste hierarchy than preventing or minimising FLW, but they provide opportunities to use FLW as a resource and provide an alternative to landfill when other, better, options are not possible (European Commission Joint Research Centre, 2020).

The interventions considered are organised based on the type of capital that they primarily engage, i.e. human, social, natural, physical or financial. Some capital categories have been subdivided because the interventions are very different and fall into distinct subcategories. For example, human capital can be divided into research interventions and knowledge and skills development.

4.1 Natural Capital

Natural capital comprises those interventions that engage producers' capacity to manage the natural resources available to them to avoid FLW. The interventions, described in Table 4.1, are primarily relevant for producers and producer support organisations and government bodies, e.g. Teagasc, BIM, the IFA and the DAFM.

4.2 Physical Capital

Physical capital comprises those interventions that develop producers' capacity to manage the physical resources available to them to avoid FLW, e.g. infrastructure or appropriate use of equipment. The interventions, described in Table 4.2, are primarily relevant for producers, producer support organisations and government bodies, e.g. Teagasc, BIM, the IFA and the DAFM.

4.3 Social Capital

Social capital comprises those interventions that develop producers' capacity to reduce FLW by engaging their social environment or shaping the social environment to better enable FLW reduction at producer level. The interventions, described in Tables 4.3 and 4.4, are relevant not only for all actors engaged in food value chains, but also for associated support and advocacy organisations for enterprises at different stages of the value chain, e.g. producers, processors, food redistribution organisations, and for FLW reduction more generally, e.g. the Environmental Protection Agency (EPA).

4.4 Human Capital

Human capital comprises those interventions that strengthen producers' capacity to reduce FLW by applying knowledge and skills, whether of an

Table 4.1. Natural resource management interventions

Solution	Sector	Description
1.1	Horticulture, tillage, livestock, aquaculture	Widespread implementation of relevant disease and pest minimisation practices, e.g. vaccination and herd health management plans, integrated pest management
1.2	Livestock (sheep, pigs)	Reducing injury risk, e.g. pen and pasture management to remove physical risks for sheep (holes, low water troughs, etc.) and night-time monitoring of sows during farrowing
1.3	Tillage, horticulture (vegetables, potatoes)	Crop planning to minimise weather damage and the adverse impacts of difficult to predict events that incur losses/waste, e.g. timing crop harvest based on consumer demand and predicted weather events or using holistic farm management strategies such as intercropping or agroforestry

Table 4.2. Physical capital management interventions

Solution	Sector	Description
2.1	Aquaculture (oysters)	Access to multiple farm sites with a wider geographical distribution, to minimise impact of environmental damage
2.2	Aquaculture (salmon)	Adequate pen design to avoid escape
2.3	Horticulture (apples)	On-farm/mobile/trailer-drawn juicing equipment to maximise harvestable product, including through co-ownership/sharing arrangements
2.4	Horticulture (outdoor lettuce, soft fruit)	Covered cropping to reduce pre-harvest environmental and pathogen-induced damage, including totally controlled environment agriculture production systems
2.5	Horticulture, tillage	Controlled atmosphere and refrigeration technology at packhouse to reduce post-harvest environmental and pathogen-induced damage
2.6	Horticulture	Use of standardised, reusable plastic crates to reduce damage in storage and transport, thus potentially reducing retailer returns
2.7	Livestock (beef, pigs, poultry)	Housing design for disease prevention, e.g. adequate ventilation, sufficient space

Table 4.3. Collaboration and network-building

Solution	Sector	Description
3.1	Horticulture, tillage, livestock	Strengthening of farmer networks within and between value chains, i.e. between farmers at local and regional levels, to coordinate strategies to improve soil fertility and pest management. This may include collaborative land use and nitrogen management planning between farmers; identifying and strengthening processing opportunities, including co-ownership of mobile, on-farm processing technologies; manure purchase agreements; and increasing market share in short supply chains and capacity to capitalise on low-FLW production strategies, e.g. group applications for organic certification
3.2	Horticulture	Expand the reach of "gleaning" in Ireland, i.e. field-level recovery and redistribution of food that would otherwise have been wasted, e.g. potatoes that are not collected by harvesting machinery and require hand-harvesting (Woolley *et al*., 2015), by facilitating network-building between farmers, gleaning volunteer teams and food redistribution organisations that are already coordinating gleaning activities, such as FoodCloud and Falling Fruit Ireland, as well as organisations with an interest in engaging with gleaning, e.g. as a corporate social responsibility activity. This should include collaboration with international organisations with experience in gleaning, e.g. Gleaning Network EU
3.3	Horticulture, tillage	Support for greater collaboration and data-sharing between retailers and producers, e.g. real-time data about consumer purchasing, to improve farmers' decision-making capacity about crop harvesting and help them make better-informed choices about market opportunities if the harvest window is fixed
3.4	All	Facilitate network-building and knowledge-sharing throughout value chains to develop and shorten food supply chains, e.g. by strengthening producer–consumer links and by overcoming barriers to utilisation of food, e.g. using the agroBRIDGES communication and technology toolkit

Table 4.4. Legislation and regulation

Solution	Sector	Description
4.1	All	Simplify administrative procedures to further encourage producers, retailers and other food businesses to donate food instead of destroying it
4.2	All	Ban the disposal of organic waste at landfill at all stages of the food supply chain
4.3	Aquaculture (oysters)	Streamline the policy and administration process to reduce the time and administrative effort required to apply for new production site licences and for changes to licences, e.g. to install alternative infrastructure that can reduce handling stress, such as swinging cradles
4.4	Horticulture	Adapt regulations for seasonal workers in the agriculture sector to support retention of harvest staff and return of non-resident seasonal staff, e.g. through relaxed travel restrictions and streamlining documentation (e.g. tax documentation) procedures
4.5	All	Effective implementation of the Unfair Trading Practices Directive, transposed to Irish law in 2021, and monitoring of its impact
4.6	All	Restriction and/or increased taxation of chemical fertiliser and pesticide application to crops and pasture to discourage degradation of soil organic matter (which can contribute to FLW in the agriculture sector), and to reduce the burden of pollution in water bodies (which can contribute to FLW in the aquaculture and fisheries sector)
4.7	All	Better regulation of the "Irish" label in the processing sector to encourage greater use of Irish produce, e.g. higher minimum produce sourcing requirements for processed food products to qualify as "Irish"

explicit, science-based or tacit nature, including the development of scientific knowledge to enable further FLW reduction at producer level. The interventions, described in Tables 4.5 and 4.6, are relevant not only for all actors engaged in food value chains, but also for associated support and advocacy organisations for enterprises at different stages of the value chain, e.g. producers, processors and food redistribution organisations. The research priorities in Table 4.6 are based on consultation with contributors to the FLW evaluation section of this research and a review of scientific literature relevant to the Irish context. These research priorities can support better decision-making and improve technical capacity at producer level to reduce FLW and contribute to stronger capacity for FLW reduction.

4.5 Financial Capital

Financial capital comprises those interventions that improve producers' capacity to leverage financial resources to reduce FLW, including interventions that can shape the capacity of other value chain actors to mobilise financial resources to promote FLW reduction at producer level. The interventions, described in Tables 4.7 and 4.8, are relevant not only for all actors engaged in food value chains, but also for associated support and advocacy organisations for enterprises at different stages of the value chain, e.g. producers, processors and food redistribution organisations.

Table 4.5. Knowledge and skills

Solution	Sector	Description
5.1	All	Knowledge and skills development support for farmers, fishers and farm and fishing staff concerning efficient food production practices, e.g. increased harvest efficiency, crop-specific spatial and temporal planning (linked to solutions 1.1–1.3, Table 4.1)
5.2	Livestock	Support for knowledge and skills development for herd health management and loss avoidance, e.g. liver fluke monitoring and reduction methods, using the genetic index to select breeding stock with good progeny survival and use of appropriate animal husbandry facilities (linked to solutions 1.1, Table 4.1, and 2.7, Table 4.2)
5.3	Aquaculture (mussels)	Knowledge support to avoid fouling, e.g. responding to predicted biotoxin events through early harvesting
5.4	Horticulture, tillage, livestock	Provide training and knowledge support for farmers and fishers to implement information communication technologies to support decision-making about farm management and produce harvesting, e.g. camera technology and image recognition software in protected growing structures, multispectral and satellite imaging technologies, machine learning and drones for crop management, camera and sensor technology to monitor farrowing sows
5.5	Horticulture, tillage, livestock (beef, sheep, dairy)	Support for knowledge and skill development to encourage implementation of agroecological farming techniques to minimise pests and disease, and develop farmers' ability to effectively implement them, e.g. increasing soil organic matter with minimum tillage cultivation techniques and crop residue retention, and physical management of the environment, for instance by modifying humidity and employing push–pull techniques such as wildflower strips
5.6	All	Knowledge and skills support for the development and implementation of post-harvest technology and mechanisation at appropriate scales, e.g. efficient drying/treatment and partial processing
5.7	All	Knowledge support for food production and processing enterprises, including on-farm processing, community kitchens and food redistribution organisations, to increase utilisation of food that would otherwise be lost or wasted, e.g. low-quality and damaged produce. Mushroom stalks can go to the production of frozen and prepared fruits and vegetables and food preservation techniques, and fish discards can go for meat and oil extraction
5.8	All	Knowledge support to strengthen farmers' capacity to participate in farmers' markets or to offer an online market or delivery boxes, whether consumer oriented (e.g. Uganda-based Bringo Fresh and NeighbourFood in Ireland) or hospitality oriented (e.g. Waste Knot in the UK), and to enable farmers to reduce food waste by more effectively managing their stock and sales, and negotiating appropriate prices, quality specifications and packaging requirements, in addition to providing access to an alternative market for surplus/cancelled orders and otherwise wasted produce
5.9	All	Skills and knowledge support for the development of producer, processor and retailer marketing skills to promote the low-waste characteristics of produce to consumers, e.g. waste reduction through high-welfare livestock rearing in free-range poultry systems

Table 4.6. Research

Solution	Sector	Description
6.1	Aquaculture (oysters); livestock (poultry)	Research to develop oyster and turkey breeds adapted to the Irish production context (linked to solution 1.1, Table 4.1)
6.2	Horticulture, tillage	Research to develop better crop varieties that have low quality-associated losses and are tolerant of intense rainfall and other challenging weather events, coupled with good yields and disease resistance (linked to solution 1.1, Table 4.1)
6.3	Aquaculture (salmon)	Research to develop vaccines for common viruses (linked to solution 1.1, Table 4.1)
6.4	Fisheries	Research into methods to reduce the catch of non-target species to further reduce fish discarding
6.5	Horticulture (mushrooms)	Research into alternatives to peat use in mushroom production that can also improve the quantity of mushroom stalk extractable from the peat layer
6.6	Horticulture, tillage, livestock (beef, sheep)	Research to improve the viability and reliability of alternatives to chemical pesticides and livestock parasite control agents, e.g. biocontrol measures, as well as minimise trade-offs between crop rotation and exacerbation of soil-borne pests (linked to solution 1.1, Table 4.1)
6.7	Horticulture	Targeted support for research aiming to trial initiatives tackling food waste and losses at farm level, e.g. for collaborative approaches involving farmers and redistribution organisations, similar to the FareShare "Surplus with Purpose" Fund and the Company Shop Group's "Harnessing Harder to Reach Surplus" project, and farmer-led research initiatives such as the DANÙ Farming Group project. Collaborative projects between farmers and food redistribution organisations should build on the respective strengths of those initiatives, to involve farmers in the design, implementation and monitoring of FLW reduction initiatives to establish a stronger evidence base for the performance of those initiatives under differing agroecological conditions
6.8	All	Research to improve understanding of effective knowledge exchange and producer support strategies for those producers who have low adoption of FLW minimisation practices and infrastructure and who are considered "hard to reach" by traditional producer advocacy organisations, e.g. Teagasc and BIM
6.9	Livestock	Research to establish the implications of pasture management for FLW, e.g. its impact on livestock diseases that contribute to food losses and optimisation of management strategies such as post-grazing sward height on pasture productivity and soil health

Table 4.7. Financial incentives

Solution	Sector	Description
7.1	All	Financial support for farmer and fisher skills development, e.g. minimum FLW cultivation and harvest management practices (linked to solution 5.1, Table 4.5)
7.2	Livestock, aquaculture (salmon)	Incentives to support the implementation of appropriate animal management facilities and to manage pasture hazards, and financial support for the administration of high-cost vaccines, e.g. development of a pig disease programme (linked to solution 5.2, Table 4.5)
7.3	Horticulture, tillage	Incentives for infrastructure improvements, e.g. covered cropping and controlled environment structures for lettuce and soft fruit to reduce pre-harvest damage or controlled atmosphere and refrigeration technology at the packhouse to reduce post-harvest losses (linked to solution 2.4, Table 4.2)
7.4	Horticulture, tillage, livestock	Incentives to support information communication technology use for farm management (linked to solution 5.4, Table 4.5)
7.5	Horticulture, tillage, livestock (beef, sheep, dairy)	Incentives to encourage implementation of agroecological farming techniques to minimise pests and diseases (linked to solution 5.5, Table 4.5). This could take the form of results-based payment programmes and practice-specific subsidies, similar to the existing EU LIFE programme, Ireland's Organic Farming Scheme and the agroforestry grant offered through the Afforestation Grant Scheme of the DAFM
7.6	All	Financial support for implementation of post-harvest technologies (linked to solution 5.6, Table 4.5)
7.7	Horticulture	Tax credits for farmers who donate produce to food redistribution organisations
7.8	All	Financial support to existing food redistribution organisations, e.g. food banks and FoodCloud, and for the establishment of new food redistribution organisations at a local level, to increase capacity to coordinate agricultural food surplus redistribution
7.9	All	Financial supports to promote expansion of domestic food processing in all sectors and incentivise processing of produce that would otherwise be wasted (linked to solution 5.7, Table 4.5)

Table 4.8. Market-based solutions

Solution	Sector	Description
8.1	Horticulture (potatoes), tillage	Implementation of short supply chain support measures, such as city region food systems[a] (e.g. Local2Local), direct sales platforms (e.g. Bringo Fresh; see solution 5.8, Table 4.5) and public sector support for purchasing regional food in municipal service offices (e.g. the Lausanne Sustainable Collective Catering Plan), to incentivise a shift in production practices, i.e. a return to a shorter period from harvest to sale to avoid storage losses, particularly for potato and tillage crops. This can be supported by communication and technology tools to support shorter supply chains, e.g. the agroBRIDGES toolkit (linked to solution 3.4, Table 4.3)
8.2	All	Strengthen coordination between producers to build capacity to engage with short supply chain initiatives such as farmers' markets and cooperatives, community-supported agriculture and online market/delivery box systems, and to digitally link processors, including small-scale processors, with farmers to enable rapid transfer of produce and a shorter supply chain, similar to consumer-oriented online marketplaces (linked to solution 5.8, Table 4.5)
8.3	All	Establish food-processing communities in rural locations where producers are highly concentrated, e.g. mobile, retractable processing facilities (linked to solution 2.3, Table 4.2)
8.4	Horticulture, tillage, livestock (beef, sheep, dairy)	Certification of "biological practices" and/or "integrated farming" to support good cultivation practices, like the UK's Linking Environment and Farming (LEAF) certification, to add value to agricultural practices incorporating good production practices including those that reduce and eliminate FLW, e.g. improving soil quality, using integrated pest management, implementing high-welfare livestock production systems
8.5	All	Stimulate uptake of retailer- and processor-level initiatives to apply their influence to reduce upstream FLW (linked to solution 3.4, Table 4.3), e.g. agreements with targets to reduce waste in the value chain, championing Irish producers and products and promoting products and production strategies that reduce FLW. This should include joint agreements and marketing effort at processor, retailer and government levels

[a]This measure strengthens rural–urban linkages to develop resilient and sustainable food systems.

5 Conclusions

The FLW database developed during the Efficient Food project has identified the problematic areas in Irish primary production food sectors. The in-depth database, summarised in Table 3.1, quantifies FLW in livestock farming, horticulture, tillage, fishing and aquaculture, and includes detailed reasons for each type of FLW identified. For each of these food sectors, the specific foods chosen for the study were those with the largest production quantities in Ireland. The research was carried out mainly through interviews with representatives from stakeholders such as Teagasc, the IFA, BIM, the DAFM, the Marine Institute, the IFI and the SFPA and numerous individual producers (farmers, fishers and growers).

The data gathered show that the annual FLW arising from primary production in Ireland amounts to 189,485 tonnes and the main problem area is the horticulture sector, in which FLW can average up to 40% in the case of some vegetables. The main reasons for this are twofold. First, retailer contracts with producers contain strict specifications on price and quality, and can also include clauses allowing them to cancel orders at the last minute. The second reason is a lack of ecological and sustainable farming methods, which degrade the soil over time, creating weakened agricultural systems that constantly need to be artificially “repaired”, for example by using synthetic fertilisers. Most interviewees deemed this as an unavoidable loss and were of the opinion that improving their farming methods was economically impossible given the current price for food paid by processors and retailers in conventional supply chains.

Overall, there were no significant data gaps in the FLW mapping exercise. One minor concern in the case of the meat production sector is the occurrence of deaths from undiagnosed causes, but these are not common, as all major diseases are under control. Mortality among very young animals is high, but it is difficult to quantify avoidable mortality, as natural death is very common in animals of this age. There did not seem to be any major issues in the non-meat part of the animal husbandry sector. The tillage sector (grains and legumes) appears to be well understood, but produce is largely not intended for food. In the horticulture sector, opinions from several different stakeholders (farmers, IFA Horticulture Committee, Teagasc and the Horticulture Industry Forum) were generally consistent and therefore the data gathered on the current knowledge of the sector are considered accurate. In the fishing sector, one possible data gap results from the disconnect between primary producers and their representing national bodies and research organisations. It appears that lack of trust and communication has led to missing information, but mitigation actions seem to be in place and the losses and waste occurring in this sector are both minimal and under control. A second unquantifiable issue in this sector is the food loss caused by pollution and climate change, which have led to uninhabitable areas and fish deaths. Unknown losses from pollution and climate change may also be present in the aquaculture sector, but it is difficult to distinguish between these and any losses associated with oyster handling and grading practices. Overall, reliable data were obtained for all the foods investigated, and thus the interview technique used throughout the data-gathering process proved to be highly effective. Furthermore, the method is recognised and approved by the European Commission and can be used in the required reporting on food waste in 2022 (EC, 2020b).

The solutions proposed in this report have been identified and described with the Irish production context in mind. The solutions described in Chapter 4 aim to leverage the natural, physical, social, human and financial capital within value chains to strengthen producer capability to reduce FLW. They focus largely on those areas of primary sector food production in which the greatest volumes of FLW occur, i.e. field and covered crops and animal husbandry, including non-meat animal-based products. There are fewer solutions relevant to aquaculture and fisheries owing to the low volume of FLW associated with those activities. From the analysis in this report, it is evident that reducing FLW in the primary production sector delivers both private and public benefits, in terms of increased efficiency and therefore profitability for farmers and fishers, without requiring an increase in the scale of production or the intensity of environmental resource extraction and production of environmental externalities such as greenhouse gases and leaching of nitrates into water bodies. It is also possible that FLW reduction at the primary production level can translate into greater accessibility of fresh and nutritious produce for consumers, including those experiencing food poverty, when total value chain and landscape governance approaches are considered, especially in the context of horticultural produce.

6 Recommendations

The interventions described in Chapter 4 of this report identify a range of tools that can be leveraged to achieve reductions in FLW at the primary production stage. As described in section 2.2, these solutions have been evaluated in terms of their contribution to producers' capabilities to address FLW, through their implications for five dimensions of producer capital, namely human, social, natural, physical and financial capital. In this chapter, the solutions are combined to create three primary policy recommendations that form a pathway to reducing FLW in the primary production sector and have implications for other stakeholders in food value chains:

1. maximising implementation of widely endorsed low-FLW production strategies (embedding low-FLW practices);
2. enhancing efficiency through sustainable intensification of production (sustainable intensification);
3. total value chain and landscape-level governance, including intervention to achieve change in the socio-ecological context of primary production FLW (disrupting food production dynamics).

These three key recommendations differ in their objectives but are complementary and can be pursued simultaneously to achieve reductions in FLW. The policy recommendations and their relationship with the five types of capital addressed by the solutions in Chapter 4 are shown in Figure 6.1.

The recommendations described below are synergistic in their contributions to Ireland's ambitions for sustainable development of the primary production sector and the broader economy in the coming decades. These ambitions include measures to "green" the agricultural sector and the broader economy and to reduce the negative impacts of agriculture on the environment, for example the Climate Action Plan, the Nitrates Action Programme, the Strategy for Development of Ireland's Organic Sector 2019–2025 and the environmental protection dimension of FoodWise 2025 and Food Vision 2030 (Organic Sector Strategy Group, 2019; EPA, 2020; DAFM, 2021a), as well as EU objectives under the European Green Deal, Biodiversity Strategy 2030 and the Farm to Fork Strategy (EU Platform on Food Losses and Food Waste, 2019a; EPA, 2020). These ambitions can be achieved by enhancing public health and animal welfare, reducing biodiversity loss, improving water quality, increasing carbon

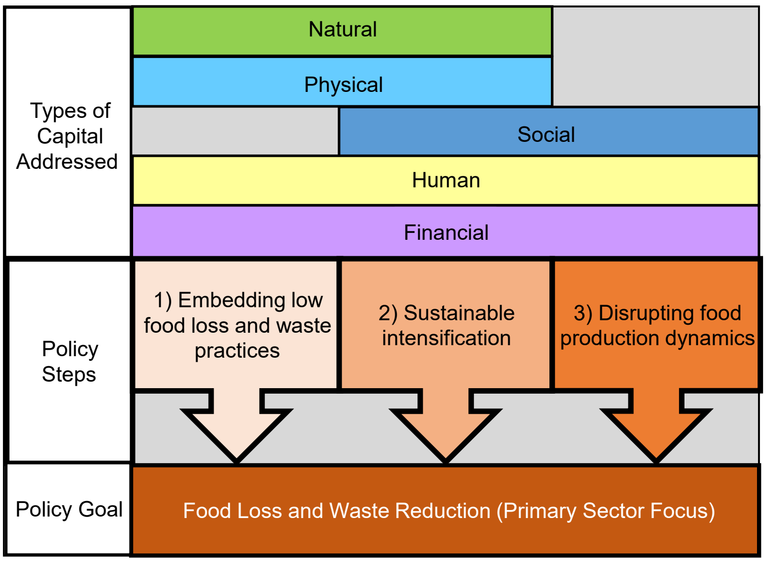

Figure 6.1. Recommended steps for reducing FLW in the primary production sector and the types of producer capital addressed at each step.

sequestration in soil, strengthening producer capability to achieve sustainable livelihoods and stimulating innovation and value creation in the agri-food sector. The recommendations therefore present a strategic opportunity for Ireland to leverage existing resources, such as the nationwide agricultural advisory service network and active stakeholders working on FLW reduction in food value chains, and to simultaneously address FLW and complementary sustainable development objectives. Figure 6.2 summarises the goals and policy actions specific to the three primary policy recommendations (objectives) described above and provides a directory to the pages on which those can be found.

6.1 Embedding Low Food Loss and Waste Practices

This report has identified a number of "low-hanging fruit", i.e. interventions that are widely endorsed by farmers and fishers and can be implemented with minimum additional resources by using existing resources, such as knowledge dissemination and exchange links between producers and producer support organisations (e.g. Teagasc, BIM, SFPA) and producer cooperatives and member bodies (e.g. IFA and the Irish Fish Producers' Organisation). These interventions aim to maximise implementation of widely endorsed low-FLW production strategies, deeply "embedding" these practices in farming and fishing systems, and the associated social norms of those systems. This step aims to consolidate the FLW reduction potential of existing acceptable and field-tested production practices, e.g. post-milking teat disinfection to reduce the risk of mastitis (Balaine *et al.*, 2020), to achieve a common, minimum standard for FLW avoidance. This approach can raise the bar for Irish production in terms of FLW reduction while contributing to other objectives, for instance food safety and animal welfare; however, it is limited in its capacity to achieve systemic FLW reduction without consideration of longer-term strategies, and value chain and landscape dynamics. This embedding of low-FLW practices step can therefore be considered an immediate but short-term contribution to FLW reduction, as it delivers results by expanding on existing programmes and activities concerning the primary production sector, but it falls short of the potential achievable FLW reduction. Indeed, in the case of antibiotic use and chemical-based pest control strategies, in particular, there is a risk of declining efficacy of these actions if they are used excessively or if resistance develops, and this can have negative implications for public health, environmental quality and farm profitability (Pimentel and Burgess, 2014; Pretty and Bharucha, 2015).

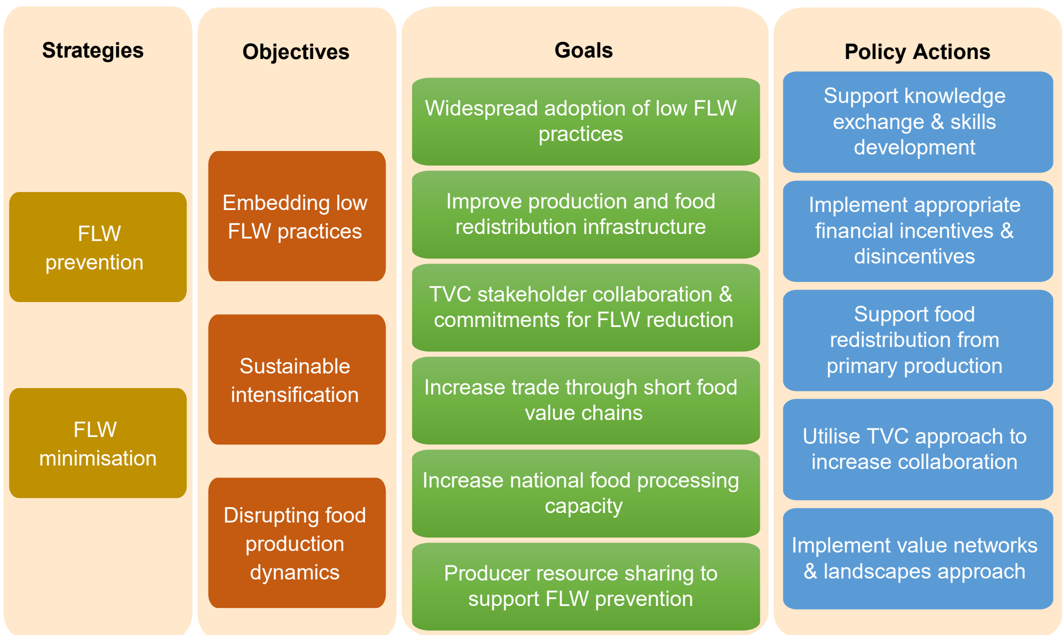

Figure 6.2. Summary of policy recommendations, including goals and actions, and directory of supporting information and evidence. TVC, total value chain.

6.1.1 Production practices

Livestock and aquaculture

Disease and pest minimisation strategies are an essential element of any plan to reduce FLW in animal-based agriculture and aquaculture (solution 1.1, Table 4.1). In livestock and salmon production, vaccination against common viruses is an essential basic strategy that is widely adopted, but full adoption is limited by the expense of some vaccines. Biocontrol measures, such as the use of wrasse to control sea lice, also contribute to reduced stress and disease in salmon production. Additional measures to avoid disease in livestock are the development of herd health management plans, including appropriate antibiotic and hygiene measures, and measures to reduce parasite load, e.g. anthelminthics, paddock rotations and liver fluke monitoring. The use of disease-resistant breeds, when available, can contribute to greater productivity in aquaculture and livestock farming without requiring greater inputs, and the selection of those breeds and bloodlines can be supported by the use of breeding indices supported by both progeny outcomes and genetic analysis. Appropriate nutrition management plans in sheep production, e.g. feeding based on body condition score, can reduce birthing problems and associated deaths.

Reducing the risk of injury is another important strategy to promote livestock health (pig and sheep production; solution 1.2, Table 4.1). In the sheep sector, this involves management of pens and pasture to remove physical risks for sheep (holes, low water troughs, etc.) and predator control measures, e.g. canine-deterrent fencing. In the pig production sector, minimising injuries involves night-time monitoring of sows during farrowing and environmental enrichment to reduce aggressive behaviour and cannibalism. In both sheep and pig production, these strategies are adopted to an extent, but adoption is limited by the labour-intensive nature of the practices, and environmental enrichment alone is not enough to eliminate aggression among pigs. Maintaining adequate staffing levels for herd size can enhance capacity to control disease and pest incidence. In aquaculture, the careful management of harvest time in mussel production to avoid fouling of shells could contribute further to FLW reduction, if universally adopted.

Tillage and horticulture

In tillage and horticulture production, more precise application of chemical products and employing integrated pest management strategies can reduce losses related to pests and diseases without increasing costs to the farmer and affecting the long-term sustainability of the farm (Barzman *et al*., 2015; Lamichhane *et al*., 2015). The use of non-chemical approaches, e.g. biocontrol agents, crop rotation and mulching, can also reduce the burden of pests and diseases with positive spillover effects for crop productivity (solution 1.1, Table 4.1) (Lamichhane *et al*., 2015; Rajendran *et al*., 2016). In these sectors, other strategies that can be used to reduce disease and pest levels include the use of disease-resistant varieties and frequent and strategic crop rotation. Choosing varieties that are resistant to environmental damage, e.g. lodging (including necking and brackling) of barley, is another strategy that can be expanded in the tillage sector to avoid losses related to weather events (solution 1.3, Table 4.1) (Berry *et al*., 2004).

6.1.2 Production infrastructure

Livestock and aquaculture

Appropriate housing design, including where it is combined with free-range/pasture-based systems, can contribute to disease reduction in poultry (Fossum *et al*., 2009; Lay *et al*., 2011), cattle (Lorenz *et al*., 2011) and pig production (Ekkel *et al*., 1995) (solution 2.7, Table 4.2). Animal housing designs that contribute to disease reduction, for instance through the provision of improved ventilation and adequate space for livestock, are available through farming support organisations, e.g. Teagasc. However, both renovation of existing animal housing and building new houses requires investment of financial capital and labour.

The implementation and maintenance of appropriate pen designs that can withstand extreme weather events ensure that salmon producers can avoid losses through fish escapes (solution 2.2, Table 4.2). Salmon escapes account for only a small proportion of losses, reflecting the high standards that are adopted by most of the industry, but financial and labour investments may prove a barrier to adoption among the minority of farms from which escapes occur.

Tillage and horticulture

Covered cropping is the main approach to lettuce and soft fruit production in Ireland, with extensive improvements in recent years (Bord Bia and DAFM, 2013). Greater adoption of this approach and upgrades to covered cropping infrastructure, including automated crop protection structures that respond to digital sensors by altering ventilation, lighting, temperature and other growing parameters, and totally controlled environment systems (e.g. the TCEA platform of Intelligent Growth Solutions; IGS, 2021) can improve producer capacity to reduce FLW in these value chains (solution 2.4, Table 4.2). However, these require financial and labour investment.

Controlled atmosphere and refrigeration technology at the packhouse is frequently used in horticulture and tillage production, but implementation can be increased further (solution 2.5, Table 4.2), especially among smaller producers, to avoid post-harvest damage associated with environmental conditions (e.g. moisture levels) and pathogens (Bord Bia and DAFM, 2013, 2015).

6.1.3 Policy initiatives to stimulate practice implementation

Knowledge exchange and skills development

Knowledge and skill development are needed to stimulate greater adoption of the FLW reduction practices and infrastructure improvements described above (solutions 5.1–5.3, Table 4.5). These supports need to include farm and vessel owners, as well as farm and fishery workers, to ensure implementation of FLW-reducing practices at every level of the production operation. Many farmers in livestock and tillage production already engage with farmer support organisations such as Teagasc and the IFA and participate in training programmes that are incentivised through subsidy programmes, e.g. the "Green Certificate" agricultural training course (Teagasc, 2020b), which is a prerequisite to be eligible for a number of farming subsidies. These networks can be leveraged to support knowledge-sharing about loss reduction practices and infrastructure and embed these practices more deeply. Peer knowledge-sharing initiatives, such as monitor farms and discussion groups, have had positive effects on farmer implementation of best practices in the beef, dairy and sheep industries (Hennessy and Heanue, 2012; O'Kane *et al.*, 2017; Prager and Creaney, 2017; Buckley *et al.*, 2019), and they can be promoted beyond the client base of public and private advisory service clients to incorporate more of the "hard-to-reach" farmers in Ireland (approximately 58% of farmers) who may not be motivated to expand their farming operations but who would benefit from improving efficiency (Kinsella, 2018), and to include horticulture and aquaculture producers, and fishers. This may require changes to current peer-sharing approaches, including the DAFM Knowledge Transfer programme, to make them more attractive to the target audience of farmers and fishers that currently are not implementing, or are implementing in a limited or inconsistent way, practices, technologies and infrastructure that could enhance the efficiency of their operations and contribute to FLW reduction strategies.

Improving access to remote learning facilities and a modular training design to ensure that farmers, fishers and staff spend time only on the skills they want to develop, rather than on practices they already implement to a substantial degree, can also enhance the attractiveness of training courses and structured peer-sharing initiatives that follow a discussion "programme", such as the Knowledge Transfer programme. Collaboration between public agencies, processors and producers can also have considerable influence on production practices that reduce FLW, as demonstrated by the CellCheck programme for improving milk quality. This programme is linked to milk payments and provides an incentive for farmers to improve milk quality, consequently reducing the risk of mastitis. Milk quality is assessed using objective standards (Shalloo and Geary, 2016; Balaine *et al.*, 2020) and is achieved through implementation of best practices and production standards specific to the intended value chains for dairy produce, for example as described by the Quality Assurance Standards of Bord Bia (2013, 2017).

Financial stimuli: incentives and disincentives

Despite the widespread implementation of the practices recommended in this chapter, and the economic benefits of the recommended practices and infrastructure for producers, barriers to their implementation deter producers from availing themselves of those benefits. To establish a common minimum standard of practices and infrastructure associated with low FLW across different production sectors, producers need to be supported to make changes, especially those who are slow adopters of widely accepted techniques (solutions 7.1–7.3, Table 4.7). Steps have been taken to understand the barriers that producers in some sectors need to overcome in order to reduce FLW, e.g. implementation of best practices for mastitis reduction (Jansen *et al*., 2009), and social support and knowledge-sharing play a role in overcoming barriers. Financial supports, such as the existing Targeted Agriculture Modernisation Scheme, also enable farmers to upgrade the infrastructure of their production systems more rapidly (DAFM, 2020b), while targeted incentive programmes, such as the Knowledge Transfer programme, and the Green, Low-carbon, Agri-environment Scheme (GLAS) stimulate engagement with the incentivised practices (DAFM, 2015; Bleasdale *et al*., 2020). Such programmes should be aligned more closely with low-FLW practices and infrastructure improvements, e.g. pasture management and livestock housing design to reduce diseases and parasite burdens, while continuing to focus attention on existing complementary objectives, such as the development of herd health management plans. This is especially relevant where farmers report a low return after making improvements in production practices, for example introducing free-range poultry production or implementing comprehensive pig vaccination, despite the immediate benefits of improved animal health and reduced on-farm losses. As most farming households depend on financial aid in the form of direct payments (Dillon *et al*., 2017, 2019), the coupling of financial aid with skill development programmes such as the Green Certificate could provide an additional incentive for producers to become familiar with low-FLW practices and take steps to implement them.

Existing supports can also be expanded to include value chains that have not previously been strongly engaged through these programmes, e.g. horticulture, aquaculture and fisheries, to support upgrading of fish pens and fishing nets, crop protection structures in lettuce and soft fruit production and controlled atmosphere packhouse technology in horticulture more generally.

In the farming sector, identifying a "future" for the farm, in terms of a successor, plays a vital role in drawing farmers' attention to opportunities for farm development and encouraging them to implement farming practices and infrastructure that can improve the efficiency of their farming operations (Leonard *et al*., 2017). Continued support for farm succession, e.g. the Succession Farm Partnership Scheme (DAFM, 2018), can help to attract more farmers to existing support programmes and knowledge-sharing initiatives that can help them to transition to more efficient, low-FLW infrastructure and practices. Meanwhile, theoretical and applied research seeking to understand "hard-to-reach" farmers and the communication and promotion strategies that are engaging and supportive for them, as well as expanding this work to include the fishing and aquaculture sectors, can help to provide greater insights into what incentives and supports for producers would be most effective in embedding efficiency across the primary food production sector (solution 6.8, Table 4.6).

Food redistribution

The recommendation to embed efficiency also includes strategies to integrate post-harvest food at risk of waste into the food value chain through redistribution, e.g. with the support of redistribution organisations. The costs of food rescue are absorbed by food redistribution organisations, despite the public benefit of those actions; therefore, consistent financial support from regional and national government is vital to enable food rescue to continue and to enable these organisations to improve their efficiency and modernise operations (EU Platform on Food Losses and Food Waste, 2019a,b; Bos-Brouwers *et al*., 2020). Food redistribution organisations remain a "second-best" solution to the issue of wasted food surpluses, with waste prevention and minimisation the main priorities to reduce the volume of food waste, as per the waste hierarchy (HLPE, 2014; EU Platform on Food Losses and Food Waste, 2019b; Bos-Brouwers *et al*., 2020). Financial support can include the direct subsidisation of Irish food redistribution organisations, such as food banks, FoodCloud, Falling Fruit Ireland and Foodshare Kerry, by the Irish government or county councils, to enable them to expand current activities and develop further food rescue measures, including small-scale processing facilities for minimally processed foods, e.g. drying, freezing, juicing and preserving (solutions 7.8–7.9, Table 4.7). Incentives such as tax credits can also be used to promote food donation (solution 7.7, Table 4.7) rather than disposal/ploughing food into the soil, as implemented in France (Vittuari *et al*., 2016; EU Platform on Food Losses and Food Waste, 2019a), Spain (Vittuari *et al*., 2016) and Ontario, Canada (Kinach *et al*., 2020).

6.2 Sustainable Intensification

Going beyond embedding efficiency through common minimum standards, sustainable intensification can maximise utilisation of edible produce while minimising negative impacts and strengthening positive impacts on socio-ecological systems (Campbell *et al*., 2014; Searchinger *et al*., 2019). This approach requires strategic collaboration between producers, government and producer-supporting bodies,[1] to achieve a regime shift in the Irish food production sector towards efficient farming systems that contribute to environmental protection (Searchinger *et al*., 2019).

The potential benefits of FLW prevention and reduction for producers, consumers and the environment can be realised only with investment in interventions that build producer capabilities to intensify production output in a sustainable way, with a view to long-term shifts in production systems. Such interventions include a holistic approach to building soil organic matter, farm infrastructure improvements and shifting production systems towards high-welfare livestock and seafood production, biological strategies for disease resistance and pest reduction, and landscape amelioration, including agro-forestry and the cultivation of plant species that support productivity but are typically not harvested for commercial purposes, e.g. in flower strips and hedgerows. Investment in research to address knowledge gaps and challenges concerning the implementation of some of these strategies is vital to ensure success in this area, especially the improvement of biocontrol strategies and the breeding of animal and crop varieties that are well suited to Irish production conditions in the context of both a changing climate and a move towards holistic, low-artificial-input production systems (solutions 6.1, 6.2 and 6.6, Table 4.6).

6.2.1 Production practices and infrastructure

Sustainable intensification draws on the common minimum standards described in section 6.1, but focuses on practices that build long-term sustainability, including those implemented in agroecological, organic and permaculture systems. This approach can be considered biological, as the emphasis is on biological inputs rather than synthetic products (e.g. integrated pest management rather than agrochemical pest management regimes), and holistic, as the production system integrates with and responds to local ecological factors using appropriate practices and technologies, co-creating a supportive ecological framework for production activities. Improving soil health and farm biodiversity is a crucial element of sustainable intensification, contributing to reductions in FLW while complementing national and EU strategies for the sustainable development of agriculture and conservation of natural resources, including biodiversity.[2] Soil degradation through the continuation of “business-as-usual” farming practices, e.g. seasonal soil cultivation operations, intensive grazing and land drainage, leads to a decline in the productive potential of land and, consequently, a decline in the yield and nutritional quality of crops. This has implications not only for crop and animal health and, consequently, FLW, but also for human and environmental health (Lal, 2009; Gregory *et al*., 2015; Abdalla *et al*., 2018). While these issues can be “covered up” using chemical fertilisers and stringent crop and animal health management strategies (both chemical and biophysical), restoring soil quality is essential for the long-term sustainability of agricultural production systems, especially in the context of increasing food production demands (Lal, 2009).

Irish fisheries and aquaculture tend to be low-input activities. Furthermore, data collected during this project showed that these sectors generate low levels of loss and waste compared with agricultural activities. For this reason they are not a focal point of the strategy outlined in this section, although improving techniques to exclude non-target species

1 Including non-governmental organisations, semi-public bodies and research institutes.

2 For example, the Climate Action Plan, the Nitrates Action Programme, the Strategy for Development of Ireland's Organic Sector 2019–2025 and the environmental protection dimension of FoodWise 2025 (Organic Sector Strategy Group, 2019; EPA, 2020), as well as EU objectives under the European Green Deal, Biodiversity Strategy 2030 and the Farm to Fork Strategy (EU Platform on Food Losses and Food Waste, 2019b; EPA, 2020).

from catch efforts (solution 6.4, Table 4.6), in the case of fisheries, and reducing stress and disease incidence and severity, in the case of aquaculture, would reduce losses further. In the context of oyster production, access to multiple production sites with a wide geographical distribution can help farmers avoid the losses associated with environmental events that have an impact on a particular bay but do not affect other bays in the region (solution 2.1, Table 4.2). Streamlining administrative processes to obtain, revise and renew licences for oyster production sites would enable oyster farmers to more easily adjust their production technologies to improve oyster health, for example by using swinging cradles (which cannot be implemented without revision of the production licence), and improve farmers' capabilities to produce at multiple distributed sites. This minimises the production losses associated with environmental stresses, rather than depending on single production sites that may be devastated by a local weather event (solution 4.3, Table 4.4).

The appropriate management of fertilisers – including livestock manure – and limited, strategic use of pesticides and antibiotics can contribute not only to reductions in FLW in agriculture, but also to improvements in water quality. This has implications for freshwater and near-shore fisheries and aquaculture, which have experienced reductions in fish stocks, including seed mussels, and production challenges because of riparian and near-shore pollution. Similarly, mitigation of carbon emissions through the sustainable intensification of agriculture has positive implications for FLW reduction in aquaculture, as the Irish aquaculture sector is highly vulnerable to climate change because increases in the frequency of extreme weather events and higher water temperatures can exacerbate disease outbreaks and induce stress. These changes can lead to increased pre-harvest mortality, and, in the case of salmon, extreme weather events can introduce greater risk of escape from pens.

Agriculture

Livestock producers can take action beyond the herd health management practices described in section 6.1 to improve animal welfare, for example by creating low-stress production environments using multispecies pasture with adequate shade and water, and good footing (Herzog *et al.*, 2018; Alothman *et al.*, 2019). Comprehensive nutrition management strategies that attend to micro-nutrient balance and intestinal and rumen health can also improve the welfare of grazing livestock (Herzog *et al.*, 2018; Alothman *et al.*, 2019). In the case of poultry, animal welfare is promoted by managing growth rate through breed selection and nutrition management, and maintaining a natural laying cycle for laying hens (solution 1.1, Table 4.1) (Whitehead, 2002; Bain *et al.*, 2016).

In the context of grazing livestock, soil health improvement can contribute to improved pasture productivity, and enable greater access to pasture, with positive implications for animal health (solution 1.1, Table 4.1) (Russell and Bisinger, 2015). This can be achieved through nutrient management plans that emphasise integrating biological fertiliser and other organic matter into the soil, and minimum tillage approaches when sowing new pasture (Rajendran *et al.*, 2016). Diverse pasture species that combine a variety of functional species, e.g. nitrogen-fixing species, and species with different growth habits (e.g. combining long-rooted and shallow-rooted grasses and herbs) can enhance soil health in terms of not only fertility, but also stability, drainage and biological activity (Sanderson *et al.*, 2007; Xu *et al.*, 2018). Multispecies pasture and the associated improvements in soil health can contribute to improvements in pasture productivity, as well as enhancing the nutritional quality of pasture (Sanderson *et al.*, 2005; Grace *et al.*, 2018; Alothman *et al.*, 2019). Furthermore, investment in pasture sustainability and maximising pasture as livestock fodder has positive implications for herd health and consequently FLW, for example by reducing the incidence of mastitis (Levison *et al.*, 2016; Van Amburgh and Cooke, 2017; Alothman *et al.*, 2019). Careful management of grazing and silage production is also essential to ensure pasture longevity and soil stability, with further investigation required to establish the implications of management strategies for FLW, e.g. post-grazing/post-cutting grass height for long-term grass productivity and soil health in mixed-species pasture (Moloney *et al.*, 2017; Van Amburgh and Cooke, 2017; Grace *et al.*, 2019) (solution 6.9, Table 4.6). Multispecies cropping systems producing diverse crops, e.g. grains and field vegetables, also contribute to reducing pest and disease levels in tillage and horticulture systems and can strengthen crop productivity (Barzman *et al*., 2015; Castellano-Hinojosa and Strauss, 2020). Cultivation practices to diversify cropping systems can include intercropping, under-sowing, agroforestry and hedgerow planting, "buffer" zones of non-harvest species and wildflower strips (Barzman *et al*., 2015; Castellano-Hinojosa and Strauss, 2020).

Soil health improvement is also an essential strategy for tillage and horticultural field crops, to achieve sustainable intensification. Zero tillage and minimum tillage systems are of particular importance in these systems because harvesting and replanting are frequent, and ploughing and harvesting operations cause mechanical degradation of the soil structure (Rajendran *et al*., 2016). It is essential to incorporate organic matter from both animal-based sources, e.g. slurry and farmyard manure, and plant-based sources, e.g. green manure and seaweed, into the soil to improve soil structure, fertility and biological activity (Diacono and Montemurro, 2011). Soil health and biological activity contribute to plant vigour and health and the suppression of soil pests and disease through competition and predation. This can reduce both the occurrence of pests and diseases in the crop environment and their effect on crop productivity (Altieri and Nicholls, 2003).

Farmers can take further steps to minimise pre-harvest losses by planning their crop sowing and harvest schedule and by developing strategies to minimise weather damage, e.g. early sowing and under-sowing of crops, sowing crops in small areas to minimise losses associated with heavy rainfall events and timing crop harvest to match expected weather conditions (solution 1.3, Table 4.1) (Borodin *et al*., 2014; Barzman *et al*., 2015). Incorporating information communication technology tools in farm management can help support farmer decision-making about crop management and produce harvesting, e.g. using camera technology and image recognition software in protected growing structures to monitor plant health and growth; digital sensors in fields to manage moisture, temperature, pH and other growth parameters; and decision support software that utilises diverse imaging technologies, machine learning and drone technology for crop protection and harvest prediction. Expansion of available information technology systems can also contribute to FLW reduction, e.g. digital and thermal imaging to monitor poultry health and detect disease and injuries (Astill *et al*., 2020), electrode-based health and milk quality monitoring during milking (Shalloo *et al*., 2021) and GPS-enabled sensors to monitor livestock movement, which can contribute to the early identification of production-related diseases such as lameness and mastitis (Shalloo *et al*., 2021), and the rapid detection of sheep flock location and behaviour (Fogarty *et al*., 2018). In-field digital sensors to monitor moisture, temperature, pH and other growing parameters, and the use of decision support tools that utilise imaging technologies (multispectral, hyperspectral and satellite imaging) and machine learning, can help farmers make better decisions about pasture management and predictions of silage harvest (Shalloo *et al*., 2021), as well as automating management decisions, e.g. housing ventilation (Astill *et al*., 2020).

Post-harvest losses can also be minimised by a farmer's decision-making before sowing (solution 1.3, Table 4.1). Successively sowing crop areas creates the conditions for a staggered harvest that can reduce on-farm harvest storage time to reduce moisture- and respiration-associated losses, particularly for those crops that are typically stored for long periods before sale and for which varieties exist that are best suited to different seasonal conditions (winter/spring, early/late), e.g. potatoes, cereals, legumes and oil crops (Alamar *et al*., 2017; Larsen *et al*., 2017). In tillage and soft fruit production, choosing crop varieties with fruit and seed qualities that enhance full crop utilisation can reduce FLW, e.g. oilseed rape varieties that resist pre-harvest shelling and strawberry fruits that are easily picked and less susceptible to handling damage (Aliasgarian *et al*., 2015).

Other adjustments to reduce FLW in the horticulture sector include on-farm micro-processing equipment, e.g. juicing and freeze-drying equipment, that can support short value chain, "farm-fresh" provisioning and help producers to add greater value to their product at the farm level, while reducing FLW associated with storage and transport. For example, mobile or trailer-drawn juicing equipment can maximise product from harvest without risking any further damage to bruised produce (solution 2.3, Table 4.2). The use of standardised, reusable plastic crates for packing produce can also reduce post-harvest losses associated with storage and transport (solution 2.6, Table 4.2).

6.2.2 Policy initiatives to stimulate practice implementation

Knowledge exchange and skills development

As stated in section 6.1, investment in knowledge-sharing and practice-stimulating initiatives is required to strengthen producers' capabilities to intensify their operations in a sustainable way and thus reduce FLW. Knowledge-sharing can take place through existing programmes, such as farm advisory services and training programmes, farmer discussion groups, public–private partnership delivery, e.g. General Mills' "Soil Academy" workshops, and farmer action research groups such as DANÙ (Wallis *et al*., 2019) and the EU-funded BASE (Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe) (BASE, n.d.) Knowledge-sharing and training initiatives need to include horticulture, aquaculture and fishery operations, and farm and vessel staff, in recognition of the influence of farm worker skill on FLW levels. Incentives such as subsidies and discounted costs for participation in knowledge-sharing and training initiatives can encourage more producers to engage with such initiatives. Greater farmer engagement with knowledge-sharing and training initiatives related to sustainable intensification could be achieved through integration with the minimum training requirements for application to subsidy programmes, similar to the Green Certificate (Teagasc, 2020b), which is currently a minimum requirement for application for various DAFM farm subsidies. As described in section 6.1, appropriate delivery methods, e.g. modular design and remote access, can also enhance producer engagement with knowledge-sharing and training initiatives. For farm and vessel staff, a meaningful certification programme that is recognised at least at the national level, and preferably at a regional level, e.g. EU, or international level, can provide an advantage to staff and employers and acts as a further incentive to access such training. Employers, e.g. fruit farmers, can more easily identify skilled labour to meet the seasonal demands on their operations, while farm workers can improve their mobility within Ireland or within Europe with a recognised certification standard attesting to their skills, thus improving their earning capacity. As implemented in Australia and New Zealand (Australian College of Agriculture and Horticulture, 2020; Primary ITO, 2021), and under way in the Irish dairy sector (DAFM, 2018), training systems that present a clear "career ladder" for primary production sector workers can cumulatively build towards a higher-level qualification that can help workers secure longer-term and better-paid positions, e.g. in farm management.

To achieve sustainable intensification using the pre-harvest and post-harvest practices described above producers need support to develop the necessary skills (solutions 5.1 and 5.4–5.6, Table 4.5), including skills in improving soil health management, in multispecies pasture and cropland management, in spatial and temporal planning for specific crops, in the application of information communication technologies to protect crops and livestock and in the implementation of on-site processing such as drying and juicing. Maintaining an effective staff team can contribute to the long-term sustainability of production operations with hired staff, whether long-term or seasonal, and training in human resource management can contribute to best management practice by farmers and fishers.

FLW reduction through sustainable intensification can be further stimulated through supports to ease the transition to biological farming alternatives, as described above, coupled with restrictive measures, e.g. restriction or taxation of synthetic fertiliser and pesticide applications, that can further encourage biological strategies for pest and disease management (Lefebvre *et al*., 2015) (solution 4.6, Table 4.4).

Financial stimuli: incentives and disincentives

Implementation barriers for farmers and fishers can be addressed with direct financial support that is integrated in existing measures, e.g. the support for organic farming in the Targeted Agricultural Modernisation Scheme (DAFM, 2021b), or that targets specific practices, e.g. agroforestry grants (DAFM, 2020c), as well as incentives promoting the measures described above, such as results-based agri-environment payment schemes which can be tailored to regions, e.g. the Burren Life programme in the Burren region of County Clare, and production systems, e.g. commonage framework plans for sheep production systems (Bleasdale *et al*., 2020) (solution 7.5, Table 4.7). Adoption of technologies for FLW reduction, including information communication technologies, can be incentivised through both financial supports and technology-linked skills development, and provide at least a part of the means to overcome investment barriers associated with adopting or expanding technologies (solutions 7.4 and 7.6, Table 4.7).

Existing regulatory frameworks for farming and fishing can also be adjusted to enable farmers and fishers to reduce FLW in a systematic and sustainable way. Establishing a national standard for products from biological and holistic systems can help reduce consumer confusion from diverse certification standards and production information and therefore support market share growth for products from sustainable production systems, e.g. the German “Bio” label for a range of biological, organic and other ecologically friendly farming standards (Oosterveer and Sonnenfeld, 2012). Streamlining documentation procedures, e.g. migration requirements and tax administration, for agricultural and fishery workers can help farmers recruit and retain skilled staff for periods of seasonal labour demand, e.g. harvesting (solution 4.4, Table 4.4).

Investment in research to support the sustainable intensification of agriculture and the systemic reduction of FLW in farming and fishing operations, including pilot trials, “proof-of-concept” studies and effective dissemination of results, is a vital element of a comprehensive policy to address FLW in primary production and promote producer adoption of the findings (EU Platform on Food Losses and Food Waste, 2019a). Table 4.6 describes a number of research priorities for addressing FLW. As described in solution 6.7, co-creation and trialling of innovations to reduce FLW using collaborative research approaches between producers and other value chain actors, e.g. food redistribution organisations, such as the Department of Environment, Food and Rural Affairs and the FareShare “Surplus with Purpose” research funds in the UK, and producer-led action research, e.g. the DANÙ farmer research initiative to trial biological farming practices in Irish production systems, can optimise FLW reduction strategies and enhance their likelihood of successful adoption (Berthet *et al*., 2018). A number of the research topics listed in Table 4.6 align with existing policies, e.g. the EU Farm to Fork Strategy (solutions 6.1 and 6.3), the Sustainable Use of Pesticides Directive (solution 6.6), the Landing Obligation of the Common Fisheries Policy (solution 6.4), the conservation of peatlands as outlined in Ireland’s Climate Action Plan 2019 (solution 6.5) (Government of Ireland, 2019), and Food Vision 2030 (solutions 6.6 and 6.8) (DAFM, 2021a).

6.3 Disrupting Food Production Dynamics

This study found that the total potential FLW reduction at the primary producer level is not achievable through the agency of producers alone, and certainly not on an individual farm basis. To achieve the greatest benefit in terms of FLW reduction a response at the level of the total value chain for each product type, and within food production landscapes, is required. This calls for a disruption of food production dynamics in ways that have influence on the socio-ecological context of primary production and can consequently reduce FLW.

The horticulture sector, in particular, is subject to volatility in consumer demand, and producers have little negotiation power with downstream actors in the value chain, such as retailers, leaving them vulnerable to unfair trading practices, even in countries where regulatory instruments prohibiting unfair trading practices are in place (Piras *et al*., 2018). The processing sector in Ireland has limited capacity to handle the volume of produce that could be used for processing and requires strategic policy support to achieve the great potential it has to offer in terms of avoiding food waste. Ireland has strong partners in the active food redistribution organisations which are undertaking innovative strategies to increase the utility of produce, e.g. by establishing a gleaning network to improve the use of the crops sown (EU Platform on Food Losses and Food Waste, 2019b).

6.3.1 Total value chain approach: stakeholder collaboration and joint commitments

Evidence from international efforts suggests that coordinated effort from all value chain members can help to address barriers to FLW reduction at various points in the value chain, including primary production (solution 3.4, Table 4.3), e.g. through voluntary agreements such as the Courtauld Commitment in the UK (Vittuari *et al*., 2016) and through value chain-specific forums such as the Irish Horticulture Industry Forum. Initiatives to support total value chain collaboration for FLW reduction should include all relevant actors, including producers, producer advocacy and support organisations (e.g. BIM, Teagasc, IFA), hauliers, processors, retailers, hospitality and consumer organisations, food redistribution organisations, animal feed processors and waste disposal organisations, with a view to setting common goals and targets within value chains, and action plans for how to achieve them. Procurement standards of downstream value chain actors can prove challenging for producers, especially in the horticulture sector, in which standards may be relaxed when consumer demand is high and tightened if demand is low, even though producers have an obligation to provide products of a minimum quantity (Piras *et al*., 2018; EU Platform on Food Losses and Food Waste, 2019a). Additional trading practices that result in avoidable FLW and are considered "unfair trading practices" include late cancellation, last-minute modifications and order rejections (Vittuari *et al*., 2016; Piras *et al*., 2018). Voluntary agreements can help to eliminate unfair trading practices, while the effective implementation of the Unfair Trading Practices Directive and the monitoring of its impact can also address this issue and strengthen the negotiating power of producers and producer cooperatives (solution 4.5, Table 4.4) (Piras *et al*., 2018; EU Platform on Food Losses and Food Waste, 2019a).

Legal obligations for retailers to prevent or donate unsaleable food, including that which does not meet quality standards, can also have an upstream influence (EU Platform on Food Losses and Food Waste, 2019b). Administrative procedures can be simplified to encourage retailers and companies to donate food instead of destroying it (solution 4.1, Table 4.4), e.g. legislating to reduce retailer and processor food waste through prevention and donation, as in Italy and France, prioritising the recovery of food for human consumption, and improving efficiency throughout the whole food value chain (EU Platform on Food Losses and Food Waste, 2019b).

Collaboration between retailers and producers is essential for strengthening producer decision-making capacity about managing their production system to reduce FLW and increase efficiency. Information-sharing between retailers and producers about customer demands and the impact of external factors on customer demand, e.g. weather and global events, can enable better decision-making by tillage and horticulture producers about sowing and harvesting that can translate into FLW reduction and more profitable harvests (solutions 1.3, Table 4.1, and 3.3, Table 4.3) (EU Platform on Food Losses and Food Waste, 2019a). Despite the powerful influence of retailers on European food production systems and trading relationships, transparent and well-communicated voluntary agreements that support producers to reduce FLW can also strengthen the corporate social responsibility image of retail and processor brands (solution 8.5, Table 4.8), providing benefits for both producers and downstream actors, and also public benefits (Oosterveer and Sonnenfeld, 2012).

6.3.2 From value chains to networks and landscapes

Shifting from a value chain approach to a food value network perspective can open up the possibility for novel collaborations between food production and consumption actors, and shift the recognition of value creation from the traditional linear model, in which value is accrued as food moves downstream, to a more dynamic and equitable approach in which value, and corresponding network "power" (i.e. negotiating capacity), can flow between upstream and downstream actors with greater fluency (Glin, 2014). The rebalancing of power in the food supply chain enables recognition of the "story" of food and the value created by discursive tools, such as "local" labels or labels indicating regional or traditional production techniques (e.g. protected designation of origin), and enables other diverse food production and consumption stakeholders to leverage discursive techniques and labels to promote those values and narratives that have traditionally been the domain of supermarkets (Oosterveer and Sonnenfeld, 2012). Shifting to a network perspective also engages the material and biological dimensions of food production and consumption processes; it brings attention to the social and ecological landscapes of food production and consumption in which interactions play out fluidly and simultaneously across multiple scales and domains, and provides new insights for FLW reduction that engage those actors to organise their interactive processes towards more efficient production and consumption of food (Oosterveer and Sonnenfeld, 2012; Pinto-Correia and Kristensen, 2013; Glin, 2014). Practical examples of such interventions, described below, include short food supply chains and increasing processing capacity and resource-sharing within food value networks. Food system disruption not only includes targeted capacity-building at specific network nodes, but can also involve restrictive interventions, e.g. banning organic waste at landfill (solution 4.2, Table 4.4), to stimulate innovation in the food value network to find alternative pathways for food that is at risk of becoming waste (Vittuari *et al*., 2016).

Short chains

Practical examples of such interventions include short food supply chains, involving greater collaboration between producers and consumers, e.g. closely connected producer-to-consumer, producer-to-catering and producer-to-processor food trading networks (solution 8.2, Table 4.8), such as traditional farmers' markets, fish markets, farm gate sales and "box" supply systems, and digital contemporaries, such as Bringo Fresh (a Ugandan producer–consumer/catering intermediary with emphasis on FLW reduction, e.g. microscale processing for unsaleable food at distribution centres) (Bringo Fresh, 2021), NeighbourFood (an Irish producer–consumer platform for farmers' market trading) (NeighbourFood, 2021) and Waste Knot (a UK producer/catering intermediary with emphasis on FLW reduction, e.g. food redistribution to the hospitality industry) (Fresh Engage Ltd, 2021). Public policymakers can support the establishment of compact networks that enable short-chain food supply through training and knowledge-sharing supports for producers and enterprises seeking to establish or participate in such networks, including formation of producer cooperatives (solutions 5.8, Table 4.5, and 8.1–8.2, Table 4.8). Short chains provide an opportunity for landscape-level FLW reduction with minimal government-level intervention, as exemplified by the Local2Local network in the Netherlands (Local2Local, 2020). Policymakers can also play a direct role in supporting short chain food supply through policies that support city-region food systems, e.g. setting targets for public service procurement from local suppliers, as demonstrated by the city of Lausanne's Sustainable Collective Catering Plan for municipal service offices (Ville de Lausanne, 2018) (solution 8.1, Table 4.8). City-region food system initiatives that connect urban food demand with local suppliers can be supported by city-region food governance networks (RUAF Foundation and FAO, 2015), such as Cork Food Policy Council (2021).

The Short Supply Chains Knowledge and Innovation Network (SKIN), SMARTCHAIN and the agroBRIDGES projects address the topic of enabling short food supply chains in Irish production systems. The SKIN project has established a "good practice" repository including Irish and international case studies (SKIN, 2020), while SMARTCHAIN hosts a database of innovations, initiatives and case studies from other European countries (SMARTCHAIN, 2020). The agroBRIDGES project aims to develop a toolkit for establishing direct relationships between producers and consumers (agroBRIDGES, 2020). Direct relationships between the producer and consumer through alternative marketplaces, e.g. community-supported agriculture and digital direct sales, enable farmers to reduce FLW associated with storage, transport and procurement standards by more effectively managing their stock and sales and negotiating appropriate prices and quality specifications, and they can also strengthen consumer appreciation for FLW reduction practices.

The short-chains approach provides producers with the opportunity to easily access information about consumer demands and associated trends. This is possible not only with direct sales and community-supported agriculture, in which the consumer and producer are only one step removed or consumers contribute directly to production (such as pick-your-own systems), but also where intermediaries exist. For example, Bringo Fresh provides information to producers about consumer demand to reduce the risk of low prices and food waste caused by production surpluses. It also advises hospitality and household consumers about the sustainability of their purchasing habits, to better align consumer demand with the seasonality of produce, and also about the factors that may influence or prolong harvest in a given season to support production system efficiency and sustainability.

Short supply chains can be leveraged further to expand producer networks and enable access to alternative markets for surplus produce, cancelled orders and otherwise wasted produce, as in the model of Waste Knot, and by linking processors, including small-scale processors, with producers (solutions 5.7 and 5.8, Table 4.5).

Processing capacity

The research undertaken to develop the FLW database for the primary production sector reveals a gap in the processing role of Irish food networks, particularly for horticulture produce and some fish and shellfish species, e.g. mussels. There is strong potential for FLW reduction if domestic food processing is expanded. This could be achieved through financial supports for processing initiatives at all scales and incentivisation of the use of produce that might otherwise be wasted, e.g. mushroom stalks (solution 7.9, Table 4.7). This could also include support for "community kitchens" and other small-scale processing initiatives associated with food redistribution, such as that used by Bringo Fresh, to prolong the quality of surplus food from the horticulture sector. Rolle (2020) advocates public support for processing expansion through providing liquidity lines to banks to ensure additional working capital support for small and medium-sized enterprises and non-profit organisations in the food production and processing sector.

Processing initiatives in rural locations with high producer concentrations can provide further food utilisation options that can support compact supply networks and reduce FLW associated with storage and transport (solution 8.3, Table 4.8) (Rolle, 2020), e.g. mobile retractable stand-alone processing facilities, juicing with trailer-drawn juicing equipment and on-farm or local fruit and vegetable freezing.

Resource-sharing

Resource-sharing can take place at multiple levels within food value networks. Collaborative producer strategies are one form of resource-sharing that can enable producers to mutually strengthen their economic position, e.g. forming trading cooperatives. Group certification and cooperative coordination can also enable collaboration between farmers on a regional level to reduce the transaction costs associated with consumer-facing certification, e.g. organic certification, and maximise the value they can attain from direct sales to consumers and adoption of certification standards (solution 3.1, Table 4.3). The cooperative approach already has a strong foundation in different sectors of primary production in Ireland, e.g. the fisheries and dairy sectors. In other regions of the world, this approach has been successful in enabling smallholder farmers to adopt and maintain agroecological practices, including organic certification, and achieve wider recognition of their sustainable farming practices, e.g. the Participatory Guarantee System of the Indian Organic Farming Federation (Oosterveer and Sonnenfeld, 2012). This network-based strategy can strengthen producer capacity to address FLW through sustainable intensification.

Other types of collaboration include the sharing of technologies and physical capital. Processing capacity can be enhanced by the sharing of microscale mobile processing technologies, e.g. juicing equipment, among producers within a region (solution 2.3, Table 4.2). The capacity to implement practices associated with greater efficiency and sustainable intensification, e.g. crop rotation and integration of animal-sourced fertiliser, can be strengthened through collaborative, local-level land use and nitrogen management planning among farmers, including rotating land rental, and manure purchase agreements (solution 3.1, Table 4.3). Similarly, staff referral and training support between producers on a regional basis, e.g. between fruit and dairy operations, can support retention of skilled staff beyond the seasonal labour peaks of any single production system. Labour resources can also be shared on a voluntary basis between producers, consumers and food redistribution organisations, as in the development of gleaning initiatives to collect unharvested produce (solution 3.2, Table 4.3) (EU Platform on Food Losses and Food Waste, 2019b).

The recommendations described in sections 6.1 and 6.2 highlighted the value of knowledge-sharing for developing producer awareness and skills concerning strategies to reduce FLW. Knowledge-sharing within food value networks, e.g. between actors in the value chain, is also needed to reduce FLW at the primary production level. Labelling and certification programmes that incorporate FLW reduction practices, e.g. organic certification and "integrated farming systems" certification such as the UK LEAF certification, can valorise FLW reduction strategies by communicating them to processors, retailers and consumers, and creating opportunities to add value to the product and gain competitive advantage in the marketplace (solution 8.4, Table 4.8). Consumer-facing government agri-food agencies, e.g. Bord Bia, and processors and retailers can also play a role in promoting the FLW reduction benefits of specific production strategies, e.g. free-range poultry production, "farm-fresh" products and "farm-to-bottle" juice products, and the purchase of "irregular vegetables" or Irish-grown/raised produce (solution 8.5, Table 4.8), and should be supported to develop capacity to effectively market products associated with low-FLW production strategies (solution 5.9, Table 4.5). Better regulation of the use of the "Irish" brand by processors can encourage greater use of Irish produce and add greater value to this label as being associated with FLW reduction, e.g. higher minimum produce sourcing requirement to use the "Irish" brand (solution 4.7, Table 4.4).

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Abbreviations

BIM	Bord Iascaigh Mhara
CSO	Central Statistics Office
DAFM	Department of Agriculture, Food and the Marine
EU	European Union
FLW	Food loss and waste
IFA	Irish Farmers' Association
IFI	Inland Fisheries Ireland
LEAF	Linking Environment and Farming
SDG	Sustainable Development Goal
SFPA	Sea-Fisheries Protection Authority

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- 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 cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Food Loss and Waste from Farming, Fishing and Aquaculture in Ireland

Authors: Jennifer Attard and Tracey O'Connor

Identifying Pressures

Food waste in Ireland has been estimated at 1.1 million tonnes per year, but this excluded farming, fishing and aquaculture (i.e. primary production), as there were no data on these sectors. This research has, for the first time in Ireland, quantified and understood food waste in primary production, and is a starting point in identifying areas that need addressing. The study found that 189,500 tonnes of food is lost or wasted each year in primary production, with significant issues arising in horticulture because of conditions in contracts with retailers and a lack of ecological farming methods, resulting in the average waste of some vegetables reaching 40%. The increasing population requires Ireland to produce 25% more food by 2050. This poses challenges; for example, the agricultural sector alone is already responsible for 33% of Ireland's greenhouse gas emissions (although a goal has been set to decrease these emissions), exploiting land for intensive food production has led to soil degradation and an increase in overfishing has put several species at risk. Furthermore, food waste is a social and public health issue, as food poverty is experienced by 9% of the Irish population.

Informing Policy

The European Commission requires countries to report on their food waste volumes by 2022, including at the primary production level. Food waste measurement is an essential starting point for food waste reduction. In Ireland, government policy states that the current target is to have an overall food waste reduction of 50% by 2030, reflecting EU ambitions articulated in the Farm to Fork Strategy and circular economy legislation. This is also in line with target 12.3 of the UN's Sustainable Development Goals, which states that there must be a reduction in food losses along production and supply chains, including post-harvest losses. Primary production food loss and waste has therefore been investigated and quantified in this report. In addition, the project team has embarked on an in-depth review of the global policies and strategies in place to reduce food losses and waste. These have been compiled in this report, along with recommendations for those solutions that were deemed to be the best suited to Irish production conditions.

Developing Solutions

The waste hierarchy orders waste mitigation methods from most favourable to least favourable, in the following series: prevention, reuse (human consumption), reuse (animal feed), reuse (by-products), recycle (food waste), recycle (nutrient recovery), recovery (energy) and disposal. The project has therefore focused solely on prevention (or minimisation) of food waste and has excluded actions that divert waste to any application other than for food. The project has compiled various options for solutions available to tackle the specific food waste issues occurring in Ireland. These solutions have been designed to make use of various different types of capital: human, social, natural, physical and financial. These solutions gathered from both stakeholder interviews and the literature, were further grouped, resulting in three recommendations:(1) maximising implementation of widely endorsed low-food-loss and low-waste-production strategies (embedding low-food-loss and low-waste-production practices); (2) enhancing efficiency through sustainable intensification of production (sustainable intensification); and (3) total value chain and landscape-level organisation and intervention to achieve change in the socio-ecological context of primary production food loss and waste (disrupting food production dynamics).

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