Preventing food loss and waste in Aotearoa New Zealand

Evidence for action across the supply chain

The fourth report in the food waste series from the Prime Minister’s Chief Science Advisor, Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia.

June 2024

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June 2024

ISBN:

978-0-473-71280-8 (PDF)

978-0-473-71279-2 (Paperback)

Other reports in the OPMCSA food waste series:

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Food rescue in 2022: Where to from here?

Beyond the bin: Capturing value from food loss and waste

Food loss and waste in Aotearoa New Zealand: Towards a 50% reduction

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Front cover (top to bottom):

1. Vertical farming at The Greengrower.
2. A misshapen tomato.
3. Food leftover after a meal.
4. A typical 'best before' date on food packaging.
5. Food preparation in a household kitchen.

Mā tōu rou, mā taku rourou
ka ora te iwi

Foreword

Kia ora koutou,

This is the penultimate report in our series on food loss and waste, which wraps up with our summary report, capturing all our recommendations, published simultaneously.

We began the series by trying to understand the challenge of food loss and waste in our national context, and have since explored food rescue and ways to capture value from food that would otherwise be wasted. We have left the biggest part of the puzzle for last: prevention. Prevention is by far the most important intervention because it has the greatest potential impact on mitigating the social, economic, and environmental harms of lost and wasted food. Preventing food from being lost or wasted saves money and the environmental costs associated with its production.

We look at prevention through the lens of the supply chain. The COVID-19 pandemic illustrated the limits of our 'just in time' supply chains, encouraging a shift to 'just in case', with more food kept in stock at different points in the system. This presents new dimensions to the already challenging problem of how to avoid the loss and waste of 40% of food produced globally.

In Aotearoa, the food loss and waste challenge needs to be understood in our context as an exporter of premium produce. Our economy is built around producing more food than we can eat. When our export supply chains break down, as exemplified during the pandemic, we need mechanisms to prevent the food involved becoming waste.

No single actor in the system can prevent food loss and waste alone. It is a system problem, and so we recommend coordinated changes across the supply chain that make it easier for everyone along the supply chain to prevent as much waste as possible.

As we bring this extended piece of work to a close, I'd like to thank our large and enthusiastic reference group of researchers and stakeholders who have generously given their time to support this work. We hope it provides a useful evidence base to support a systems change to one in which less food is lost and wasted.

Ngā manaakitanga,

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Prime Minister's Chief Science Advisor
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Acknowledgements

This report was drafted by Rebecca Benson, Trixie Croad, Jacques de Satge, Lysea Haggie, Jessica O'Connor, George Slim, and Carolle Varughese. We thank interns Jackson McBreen and Megan McKenzie for their contributions to report appendices.

We thank the many academics, industry experts, entrepreneurs, and government agencies who formed our reference group. To those who met with the team, provided introductions, and generously contributed time, energy, and suggestions to this project, we are thankful for your contributions. We also acknowledge the contribution of members of the Chief Science Advisor Forum.

We have incorporated as much feedback as possible. Our acknowledgement of people who helped us with this project in no way indicates their endorsement of the final recommendations. We have done our utmost to keep track of everyone who has contributed to this work. Please accept our sincere apologies for any inadvertent errors or omissions. Any mistakes in the report are our own.

Particular thanks to

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Amanda Wolf, Victoria University of Wellington

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Kenny Lau, NZ Trade and Enterprise

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Kim Hang Pham Do, Massey University

Kirra Havemann, Sunday Blessings

Kirsten Unger, Bakeworks

Kristin Busher, Waiheke Resources Trust

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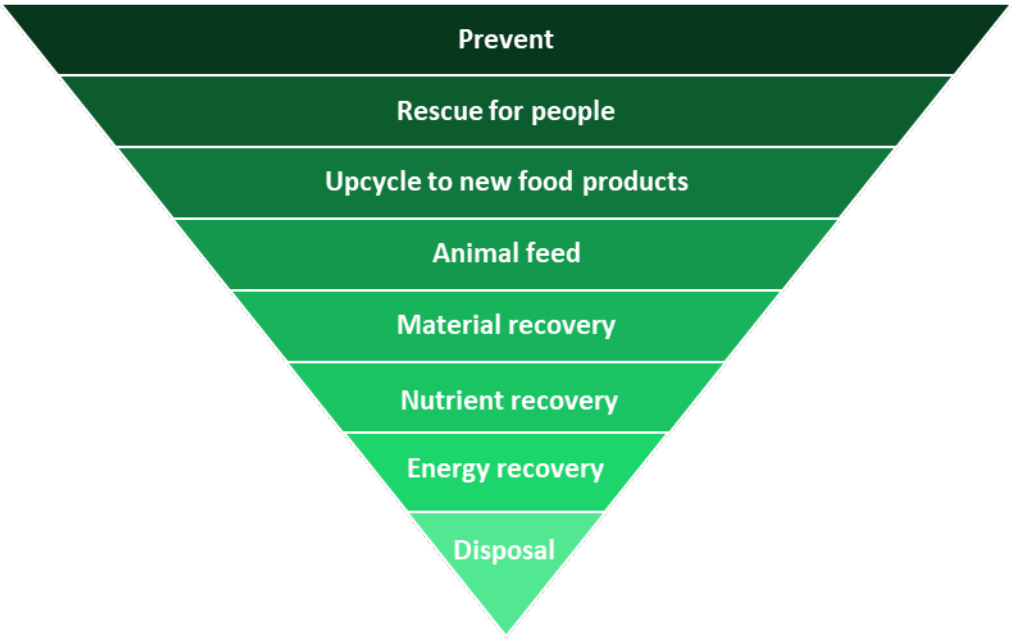
Contents

Summary and recommendations

Executive summary

The food recovery hierarchy (below) is a framework for thinking about food loss and waste (FLW). Our previous reports *Food rescue in 2022: Where to from here?* and *Beyond the bin: Capturing value from food loss and food waste* describe many ways to solve some of the problems created by FLW at different levels of the hierarchy. This report focuses on the top level of the hierarchy, prevention. Preventing FLW across all parts of the supply chain is a more effective way to save money and mitigate climate change than simply managing wasted food at the end of its life, because this prevents the unnecessary financial and environmental costs that FLW incurs along the food supply chain, as well as the financial and environmental costs of its recovery or disposal.



When we talk about prevention in this report, we mean any efforts to stop food going to lower levels of the hierarchy. For further clarity, we borrow ReFED's framing:

> *"Prevention efforts focus on interventions at the root causes of food waste—they locate and address inefficiencies in the food system and food related practices before excess food is produced, transported to places where it cannot be utilized, or discarded rather than eaten."*

Many people and businesses are involved in the pathway getting food from the place where it originates to the places where we eat it, often modifying or transforming it along the way. This pathway forms the supply chain. Emissions associated with FLW occur not only when it is landfilled, but in every stage along the chain, which is why prevention is at the top of our food recovery hierarchy.

The food supply chain is a complex system, and efforts to influence that system – like preventing FLW – need to take a systems view. The relationships between stakeholders across the chain, their relative power, and the different economic incentives they face all contribute to FLW. We can't understand why we have FLW, much less design and implement ways to prevent it, without understanding these factors. Our context in Aotearoa, where food export makes a large contribution to the economy, is an important consideration in our efforts to prevent FLW.

While we present the systems view first, we also recognise the value in looking at each stage of the supply chain in depth. Production – where food is grown and harvested – is the first stage of the food supply chain. Food loss in production includes produce that is grown for human food use and not harvested, pre-harvest losses, losses through disease and weather impacts, and food rejected on farm because of safety or quality concerns. Globally, the production stage has been identified as accounting for 25% of total FLW, the second highest proportion of FLW after households. On farm food loss is, however, recognised globally as a significant data gap. This is partly due to the difficulty of accurately measuring food loss on farms because of logistical barriers and the variability between crops. FLW that occurs in production has a complex set of interacting drivers that are often outside of the control of producers themselves. Common drivers include labour shortages, weather events, and prohibitive cost of harvest. Power dynamics in the food supply chain combined with the variable nature of weather patterns, exacerbated by climate change, often mean that producers are left with significant financial risks, which can result in overproduction as a form of risk mitigation.

The first steps in preventing food losses during production are:

- Addressing market drivers.
- Exploring the potential of cooperative business models to improve farmers' market power.
- Supporting farmers to identify and share data on their food loss occurrence.
- Enabling access to viable secondary markets, for example, for rejected fruit.
- Adoption of technology that can prevent losses pre- and during harvest.

Processing and manufacturing, the next stage of the food supply chain, involves creating new ingredients or products that often have a longer shelf life and greater consumer appeal than whole foods. Food loss during this stage is not openly shared in detail. It can occur due to the removal of parts that are not typically used or eaten; difficulties in planning inventories and matching production with demand; machine faults or human errors; and the requirement to have samples on which to carry out quality control testing and meet product specifications. Increasing efficiencies in manufacturing processes through new business practices and technology integration can help prevent unnecessary FLW within this stage of the supply chain, as well as have an impact both upstream and downstream through interactions with suppliers, distributors, and consumers.

Key to facilitating the implementation and evaluation of preventative practices by food processing and manufacturing companies are:

- Policies around waste measurement and reporting for processors and manufacturers.
- Innovation in packaging and storage technology.
- Resources for the adoption of new digital technologies.

Retail and food service sectors are uniquely positioned in the food supply chain, interacting directly with consumers and suppliers of food. As such, we can think about FLW in these sectors in two ways: waste that occurs within retail and food service sectors, and FLW that occurs up and down the supply chain but is driven by these sectors. We know little about food waste generated within retail and food service in New Zealand; extrapolation from limited studies suggests it’s significant, but less than that which occurs in households. Food waste within the retail sector is driven by a combination of operational inefficiencies like poor demand forecasting, and market-driven practices, like overstocking.

In preventing FLW upstream in the supply chain, two key levers are available to retail sectors: addressing cosmetic specifications to reduce on farm losses and improving ordering practices to limit overproduction. Looking downstream, retailers have a role to play in educating consumers and can influence purchasing decisions through their marketing strategies to help reduce food waste in stores and in households.

In food service, international evidence suggests that plate waste from consumers is the primary driver of food waste in the sector, followed by operational inefficiencies like non-optimal inventory management. Changes to the way food is offered to consumers – such as portion sizes in restaurants and cafes or the availability of trays in self-service venues – may be effective at addressing plate waste, while digitalisation could improve operational efficiency in ways that prevent food waste.

At the end of the food supply chain, households in New Zealand generated an estimated 122,547 tonnes of food waste each year, the equivalent of $872 million of edible food. This accounts for a significant portion of FLW across the New Zealand food supply chain; it is estimated to account for 40% of all FLW. However, without robust data from other parts of the supply chain, this estimate relies heavily on data extrapolated from international sources. Drivers of household food waste involve a complex interplay of behavioural, environmental, and socio-cultural factors. Interventions which empower people by giving them tools, knowledge and support, in combination with environmental modifications that promote waste prevention behaviours, tend to be more successful than information-based approaches in isolation. Policy makers can support evidence-based interventions by setting strategic direction, enacting legislation and regulation, and facilitating infrastructure and services that reduce food waste.

Scientists, engineers, and entrepreneurs, both in Aotearoa and abroad, are innovating in ways that could prevent FLW. From breeding crops with characteristics that promote shelf life, to smart packaging that can help consumers, to digitalisation that can make supply chains more efficient, and many other advances, there are abundant opportunities in this space. With the right support for both the research and innovation and food systems, we can capture these opportunities. However, some of the drivers of FLW are not amenable to technical improvements, but instead come from the structure of the market and the relationships between different actors across the supply chain. Consumer preferences and habits also play a role. These factors will need to be addressed alongside any gains we can make through scientific innovation.

There is no single cause of FLW in our food system, and so it is unlikely that there will be a single solution. There is also a lot we don’t know about FLW and that is a big part of the mission, but uncertainty doesn’t have to be a barrier to action. At the highest level, we should invest in technical and other solutions that optimise the operations of the supply chain, while also ensuring that the market is set up to incentivise prevention of FLW. Currently, economic incentives and supply chain power dynamics drive much of FLW and the costs of FLW are accrued where the FLW is realised, not where it is caused. Preventing FLW meaningfully requires a system-wide view and a coordinated and strategic approach, informed by a data-rich evidence base.

Recommendations

Recommendations are made under five themes. Each report in the series contains recommendations under these themes.* The recommendations relating to this report are summarised below.

Systems problem, systems solutions	**P1:** Utilise sector action plans (SAPs) to identify intervention opportunities that take a systems view while allowing for the unique contexts of different sectors. **P2:** Evaluate the effect of the Grocery Supply Code on trade term driven food loss and waste.
Measure and monitor	**P3:** Support the creation and adoption of a data platform for the sector.
Prevent food loss and waste at source	**P4:** Encourage novel and emergent models of food purchase by consumers. **P5:** Identify mechanisms to avoid food loss and waste caused by extreme weather events. **P6:** Update specification practices that lead to edible food being discarded. **P7:** Continue to explore alternatives to traditional date labelling. **P8:** Pursue opportunities to reduce food loss and waste through research and innovation. **P9:** Support evidence-based consumer communications campaigns.
Save good food for people	*There are no recommendations under this theme in this report.*
Capture value from unavoidable food loss and waste	*There are no recommendations under this theme in this report.*

Each recommendation contains detailed sub-recommendations. For each sub-recommendation, we provide an indicative timeframe for implementation.

- **Next 12 months** – These recommendations should be considered for immediate implementation, to capture existing momentum and make the most of low-hanging fruit.
- **By 2027-2028** – These recommendations might take a little longer to implement but should be pursued in the near term to keep Aotearoa on track to a future without food waste.
- **By 2030** – The UN Sustainable Development Goal (SDG) 12.3 calls for per capita retail and household waste to be halved by 2030, and for food loss to be reduced elsewhere in the food system. These recommendations should be considered for implementation by 2030, in pursuit of SDG 12.

* We have maintained the term "food waste" in theme names and descriptions for consistency with previous reports, but this should be interpreted to include food loss.

Theme 1: Systems problem, systems solutions

Combatting food loss and waste requires people throughout the food system and in the waste management sector to work collaboratively towards a shared vision. To achieve this, we need a national food loss and waste strategy and reduction target, and coordination mechanisms that empower stakeholders to bring the shared vision to life.

Prevention recommendations for theme 1

P1: Utilise sector action plans (SAPs) to identify intervention opportunities that take a systems view while allowing for the unique contexts of different sectors.

Next 12 months	By 2027-2028	By 2030
a) Undertake a trial SAP for one key sector.	**b)** Undertake process and outcome/impact evaluation for the SAP undertaken as part of **P1.a**. **c)** Using the learnings from **P1.b**, undertake SAPs for other key sectors.	**d)** Implement interventions identified in SAPs to support system change.

Considerations

This work could be led by the Ministry for the Environment (MfE), and informed by best practice overseas and work by the Kai Commitment in New Zealand.

It will be important to have meaningful partnership from organisations across each sector to ensure interventions identified are workable. End Food Waste Australia (EFWA) has undertaken SAPs for several sectors. These could be useful models for SAPs in Aotearoa. If resources are limited, an abbreviated process could be to seek input from sector stakeholders on the feasibility and local applicability of interventions identified in the Australian SAPs in New Zealand.

Sectors can be but don't have to be defined by food product. For example, EFWA has undertaken SAPs for bread and bakery, cold chain, food rescue, dairy, food service, and horticulture.

SAPs will be more useful if designed to include regular reviews and refreshing. **P1.d** will require a dedicated administrative body with industry buy in, as implementation processes will require coordination.

P2: Evaluate the effect of the Grocery Supply Code on trade term driven FLW.

Next 12 months	By 2027-2028	By 2030
a) Commission an evaluation designed to understand the effects of the Grocery Supply Code (the Code) on FLW.	**b)** Receive and report interim findings. **c)** Identify areas where amendments to the Code may improve results. **d)** Signal willingness to use enforcement or stronger regulation if interim results suggests that the Code is not effective.	**e)** Receive and report final findings. **f)** Consider whether updates to the Code or new regulation is necessary in light of **P2.e**. **g)** Design and implement an ongoing monitoring mechanism.

Considerations

The Code is intended to promote fairness, transparency, and certainty in the grocery market. Although not its purpose, the Code has potential to prevent FLW.

P2 could be a joint workstream between MfE and Ministry of Business, Innovation and Employment (MBIE) in consultation with the Commerce Commission. The scope of this workstream could include topics of interest to the Commission beyond FLW.

P2.a should consider the whole supply chain, as some requirements of the Code may prevent food loss upstream.

The European Commission's directive against unfair practices in the food supply chain (EU 2019/633), and the review of the Australian Grocery Code of Conduct published in 2024 that includes specific reference to FLW (page 58), may be useful background.

Theme 2: Measure and monitor

We need to know more about food waste in Aotearoa. Not just how much food is wasted, but where in the food system that waste occurs, current diversion practices, dominant food waste types, and geographic variation in waste volumes. Good data is crucial to articulating the challenge, galvanising action, designing well-targeted interventions, and monitoring progress.

Prevention recommendations for theme 2

P3: Support the creation and adoption of a data platform for the sector.

Next 12 months	By 2027-2028	By 2030
a) Undertake engagement with relevant stakeholders to identify: **i.** functional needs of the data platform; and **ii.** adoption and implementation support needs. **b)** Scope project requirements, taking into account findings from **P3.a** but also FLW and other goals, and existing technical capabilities and gaps. **c)** Identify options to support platform creation (e.g. direct commissioning, public private partnerships, support for adapting existing private sector solutions, etc.).	**d)** Pilot data platform. **e)** Design and implement a monitoring and evaluation plan for the platform. **f)** Design mechanisms to incorporate relevant advances in digital technology as appropriate.	**g)** Fully roll out platform to all businesses in the New Zealand food supply chain.

Considerations

P3 is consistent with a 2024 report from the Parliamentary Commissioner for the Environment on resource use and waste generation, which recommends "establish[ing] a formal set of material flow accounts for New Zealand".

P3 could be a workstream across central Government, to include Stats NZ, MBIE, and the Ministry for Primary Industries (MPI) and others. The EU's data platform programme may provide a model to follow. Locally, initiatives like the Trust Alliance New Zealand's Digital Farm Wallet or Stats NZ's accounting system that includes 'satellite accounts', could be scaled up or integrated into the platform.

Theme 3: Prevent food loss and waste at source

Preventing food loss and waste at the source has scope to deliver the greatest environmental, social, and economic benefits throughout the food system, and everyone has a role to play. A high degree of connectivity means that New Zealanders can contribute to food loss and waste prevention not just at their stage of the food supply chain, but throughout the system.

Prevention recommendations for theme 3

P4: Encourage novel and emergent models of food purchase by consumers.

Next 12 months	By 2027-2028	By 2030
a) Undertake scoping of models for consumer purchase outside of major supermarkets (e.g. refilleries, consumer supported agriculture, and farmers' markets) that for example can enable purchase of only desired quantities. **b)** Undertake or commission evaluation and/or evidence synthesis on the effects of these models on FLW.	**c)** Receive and report findings from **P4.b**. **d)** Informed by **P4.c**, consider mechanisms to promote a diversity of food purchase models.	
Considerations This work could be led by the Commerce Commission in collaboration with MBIE as it would fit within their remit for increasing competition in the grocery sector.		

P5: Identify mechanisms to avoid food loss and waste caused by extreme weather events.

Next 12 months	By 2027-2028	By 2030
a) Commission research to understand the food loss implications of predicted increases in extreme weather events. **b)** Use the results of **P5.a** to identify and develop interventions to prevent waste during extreme weather events.	**c)** Implement actions identified in **P5.b**.	
Considerations Extreme weather and other disruptions bring into play other tiers of the hierarchy as well. See our report *Food Rescue in 2022: Where to from here?* that includes Foodbank New Zealand, and this report.		

P6: Update specification practices that lead to edible food being discarded.

Next 12 months	By 2027-2028	By 2030
a) Explore best practice for consumer communications to make blemished products more acceptable to consumers. **b)** Support stakeholder groups working in this space to evaluate FLW outcomes. **c)** Explore mechanisms to incentivise relevant stakeholders to reform specifications practices and undertake a review of best practice for specifications.	**d)** Support businesses to undertake consumer communications. **e)** Implement relevant mechanisms suggested by **P6.c**.	

Considerations

P6.a would be part of **P9.b**.

P6.d and **P6.e** could be piloted on selected businesses or sectors before being rolled out in full.

Specifications cover appearance, taste and texture, and food safety. Taste and texture and food safety criteria are relatively fixed while appearance (size, shape, and colour) criteria are more dynamic. This recommendation is focused on the more dynamic criteria.

This recommendation will interact with recommendation **P8**, which promotes technological advances leading to more produce being 'in spec' and recommendation **P3**, which promotes all supply chain actors having access to demand forecast information.

P6 is in line with recommendations made in EFWA's Horticulture SAP. Consider replicating activities recommended in 'Action P3' of the aforementioned report.

The application of quality standards in export industries (e.g. kiwifruit), which protects the economic wellbeing of producers may have lessons for domestic markets.

P7: Continue to explore improvements to current date labelling.

Next 12 months	By 2027-2028	By 2030
a) Commission or undertake work that explores: **i.** alternatives to current requirements, including standardisation of label formatting; **ii.** the likely implications of different alternatives for waste; **iii.** the likely implications of different alternatives for food safety; **iv.** stakeholder views on uses of date labels; and **v.** evaluate the evidence base on the efficacy of consumer education programme around date labelling.	**b)** Support retailers to pilot, evaluate, and refine potential new labelling approaches, ensuring evaluation includes effect on FLW reduction. **c)** Informed by **P7.a** and **P7.b**, phase in new education and/or labelling approach.	

Considerations

There would need to be coordination with Australia if Food Standards Australia New Zealand leads this work.

Successful examples of date label reform are detailed in table 8.

A comprehensive review of international best practice for date label reform, building on table 8 would be a good first step. Note that EFWA have a current project reviewing date labelling and food storage advice. Industry as well as consumer perspectives would need to be considered.

P7.b could involve supporting an interested national retailer to undertake a pilot.

Label reform could include messaging around date labelling. The 'Look, smell, taste, don't waste' campaign in the UK may be a good example, and Aotearoa could build on New Zealand Food Safety's 2023 campaign 'Check it, sniff it, taste it, don't waste it'.

P7 would be part of **P9.b**.

P8: Pursue opportunities to reduce food loss and waste through research and innovation.

Next 12 months	By 2027-2028	By 2030
a) Prioritise funding for FLW prevention under: **i.** MfE's Waste Minimisation Fund; and/or **ii.** Government research schemes. **b)** Support research for technology that can be used on farm to prevent FLW, including implementation research. **c)** Continue to support exploration of opportunities for agri-tech addressing FLW as an export product. **d)** Explore mechanisms to support adoption of innovation by small and medium enterprises (SMEs) to prevent FLW. **e)** Ensure that public investment in research and innovation in FLW is evaluated, to realise positive outcomes.	**f)** Implement mechanisms to support adoption of innovation to prevent FLW by SMEs. **g)** Develop a strategy covering prioritisation of relevant research, mechanisms to support research and adoption of innovation, and ongoing evaluation of performance in this space.	**h)** Review and refine research strategy to meet needs post-2030.

Considerations

P8.a should align with SAPs in **P1**, to ensure coordinated funding.

P8.b-e could be achieved through mechanisms such as the MPI-administered Sustainable Food and Fibre (SFF) Futures Fund.

Note that opportunities for research and innovation to reduce FLW and its related harms go beyond prevention of FLW.

P8.c would allow innovation and technology development that is unlikely to be sufficiently profitable at the New Zealand scale. There is a trade-off between the benefits of the technology to New Zealand producers and the benefits of exporting the technology to its developers on one hand, and the risk of losing competitive advantage by making our innovations available internationally on the other.

P8.b and **P8.d** will include innovations around digitalising operations to enable better inventory management, demand forecasting etc., as well as innovations related to food (e.g. breeding and shelf life) and the way we interact with food (e.g. robot harvesters and smart packaging).

P8.e and **P8.f** may align with **P3.c**.

Pilot studies of innovative tools could be a useful way to evaluate effectiveness before rolling out.

P9: Support evidence-based consumer communications campaigns.

Next 12 months	By 2027-2028	By 2030
a) Scope existing work on consumer communications on FLW to identify: **i.** mechanisms to ensure their continuity and; **ii.** gaps where additional work is needed. **b)** Identify new and planned activities that would benefit from consumer communications campaigns on FLW. **c)** Incentivise robust evaluation of activities in this space.	**d)** Use evaluation findings to prioritise ongoing support.	

Considerations

P9.a should capture both national third sector campaigns like 'Love Food Hate Waste' as well as actions taken in the private sector, for example, messaging in retail settings.

P9.a.ii should consider not only specific topics or issues, but also the geography of the campaign (local versus national) and the demographics targeted.

Activities captured under **P9.b** would include **P6** (date labelling) and **P7** (quality specifications).

To achieve **P9.c**, funding could be contingent on having robust evaluation mechanisms embedded.

Theme 4: Save good food for people

Good food is not a waste stream to be managed – it is a resource for nourishing people. Surplus food, imperfect but nutritious produce, and edible by-products are examples of food, not food waste. Resources, systems, and enabling conditions that promote food rescue and upcycling are crucial to ensuring edible food is never treated as waste. If nourishing people is not practical, using the food as feed resources for animals is the next best alternative.

Prevention recommendations for theme 4

There are no prevention recommendations under this theme. See our reports Food rescue in 2022: Where to from here? and Beyond the bin: Capturing value from food loss and waste for recommendations under theme 4.

Theme 5: Capture value from unavoidable food waste

There will always be some waste in our food system, which must be managed to capture value in alignment with circular economy thinking and the food recovery hierarchy. Diversion to animal feed and investment in material, nutrient, and energy recovery from food waste will ensure there are decent end-of-life options for unavoidable food waste. Landfilling food waste has no place in our waste management future.

Prevention recommendations for theme 5

There are no prevention recommendations under this theme. See our reports Food rescue in 2022: Where to from here? and Beyond the bin: Capturing value from food loss and waste for recommendations under theme 5.

1. Preventing food loss and waste – the top of the food recovery hierarchy

The food recovery hierarchy (see figure 1) is a framework for thinking about food loss and waste (FLW). We discuss the hierarchy – and the need for nuance in its application – in *Beyond the bin: Capturing value from food loss and food waste.*

Our previous reports *Food rescue in 2022: Where to from here?* and *Beyond the bin: Capturing value from food loss and food waste* describe many ways to solve some of the problems created by FLW at different levels of the hierarchy. This report focuses on the top level of the hierarchy, prevention. Preventing FLW across all parts of the supply chain is a more effective way to save money and mitigate climate change than simply managing wasted food at the end of its life, because this prevents the unnecessary financial and environmental costs that FLW incurs along the food supply chain, as well as the financial and environmental costs of its recovery or disposal.

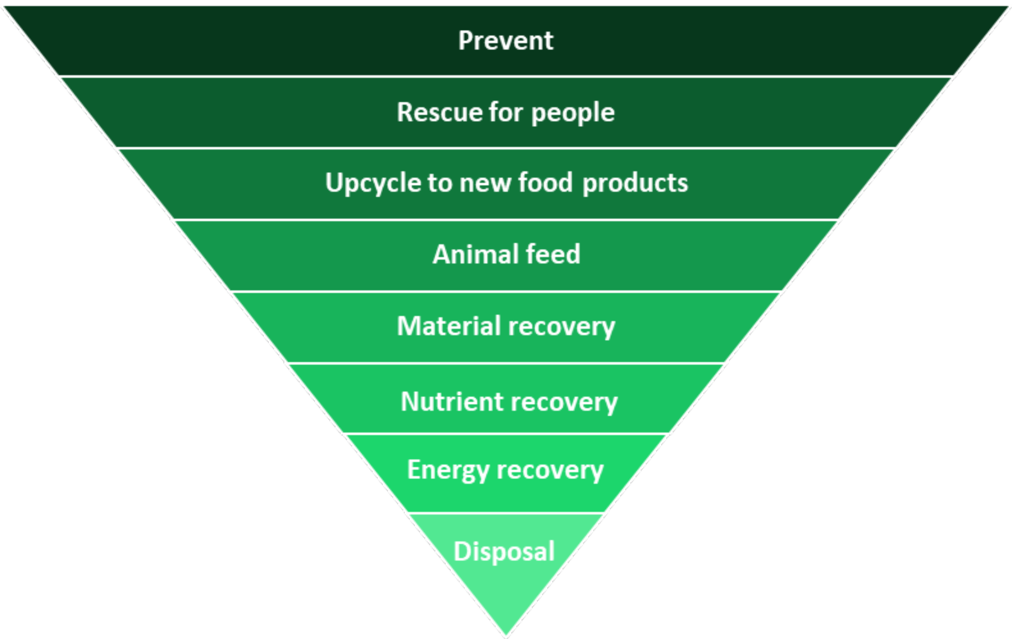


Figure 1: Food recovery hierarchy. Adapted from Teigiserova et al. and Moshtaghian et al.[1,2]

> Preventing FLW in the New Zealand context differs from many other places because we export a very large percentage of the food we produce…

Preventing FLW in the New Zealand context differs from many other places because we export a very large percentage of the food we produce (see section 1.3), estimated at 80%-90%,[3] and even higher for major sectors such as dairy at 95%.[4] In less export oriented food systems, an important component of prevention will be minimising overproduction, but that is not always financially viable for Aotearoa, given the importance of food export for our economy and the lack of visibility of the fate of our produce in the export markets.

Additionally, because only part of the supply chain for exported food is domestic, prevention of food loss upstream in the supply chain (see section 1.2) plays a greater role than in some other countries. The distance between producers and consumers also introduces uncertainties of supply and demand

and economic drivers of FLW not present in countries where most food is produced for local consumption. Prevention is challenging because it involves considering less tangible outcomes such as using fewer resources, rather than reducing waste once food has been manufactured.

1.1 Definition and scope

A precise definition of FLW prevention is more complicated than it appears at first glance.[5,6] In general, prevention means that surplus, lost or wasted food is not created. For this report, we sidestep definitional difficulties by referring to our hierarchy: when we talk about prevention, we mean any efforts to stop food going to lower levels of the hierarchy. For further clarity, we borrow ReFED's framing:

> *"Prevention efforts focus on interventions at the root causes of food waste—they locate and address inefficiencies in the food system and food related practices before excess food is produced, transported to places where it cannot be utilized, or discarded rather than eaten."*[7]

We explore the reasons food is lost and wasted at each stage of the supply chain, while noting that in some cases, FLW is unavoidable. As we discuss more in box 1, the reason for FLW is not necessarily the same as the direct cause. There are many potential interventions at different points in the supply chain, but understanding the reasons for FLW will allow us to identify those interventions with the greatest likelihood of success. No step in the supply chain can operate in isolation, so we take a whole of system view.

As we discuss in section 1.3, there is a global component to our food supply chains, as we both export and import food. For this report, we focus only on FLW that can be prevented in Aotearoa. This means consumer behaviour of export customers is out of scope, although some interventions here – for example, breeding fruit for longer shelf life – will likely have downstream effects offshore. Similarly, FLW upstream, before it reaches New Zealand, is out of scope for this report, although local importers and downstream actors could in theory include requirements around meeting FLW standards in their terms of trade.

1.2 The food supply chain

In modern Aotearoa, even those of us who hunt, fish, raise our own animals, or grow our own fruit or vegetables mostly rely on the commercial food system for the majority of our diets. Many people and businesses are involved in getting food from the land or water where it originates to the places where we eat it, often modifying or transforming it along the way. This pathway, from where food – or the raw ingredients that will become food – originates to the places where we eat, forms the supply chain. More formally, researchers have defined the food supply chain as "the movement of products along the value-added chain … that aim at realising better value for the customer alongside cost minimisation."[8]

The specific pathways differ for different kinds of food, but figure 2 shows an illustration of the supply chain that can be adapted and applied for most food products. The first stage of the supply chain is production. Production usually involves growing or raising plants or animals in a somewhat controlled environment like a farm, but would also include wild fishing and hunting, and foraging.[3] The next stage of the supply chain is processing and manufacturing. There is considerable variation in how much transformation food undergoes in processing. Some products, like fruit that will be eaten whole, need only to be sorted and packaged, while crops like wheat need to be milled to become flour and then baked to become bread. Food that has been processed and/or manufactured moves along the supply chain towards consumer-facing businesses, including retailers, restaurants, and institutions that include food service, like rest homes or prisons. Depending on the product, there may be an intermediary between the producer/manufacturer and the retailer. Finally, consumers purchase food, either to eat immediately, as in a restaurant, or to take home and consume.

Figure 2: A simplified depiction of the food supply chain. Note that we have modified the figure since we introduced it in *Food waste: A global and local problem* to group food service with retail rather than with household.

In reality, the food supply chain is more complex than figure 2 suggests. Firstly, the simplified model of the supply chain omits some actors and stages, including transport, storage, wholesale, and distribution. Secondly, the simplified version implies each actor interfaces only with other parties directly upstream or downstream, and that food products must 'touch' each stage. This is often not the case. Large supermarkets, for example, source their goods directly from producers, from processors and manufacturers, and from wholesalers and distributors. Wholesalers and distributors, in turn, can connect producers and processors or manufacturers, processors or manufacturers and retailers, or even two or more processors or manufacturers. Finally, the food supply chain features considerable vertical integration (see section 5.1). Figure 3 depicts the supply chain in a way that is closer to reality, although it is unlikely to capture every node and path through which food passes on its way to the consumer.

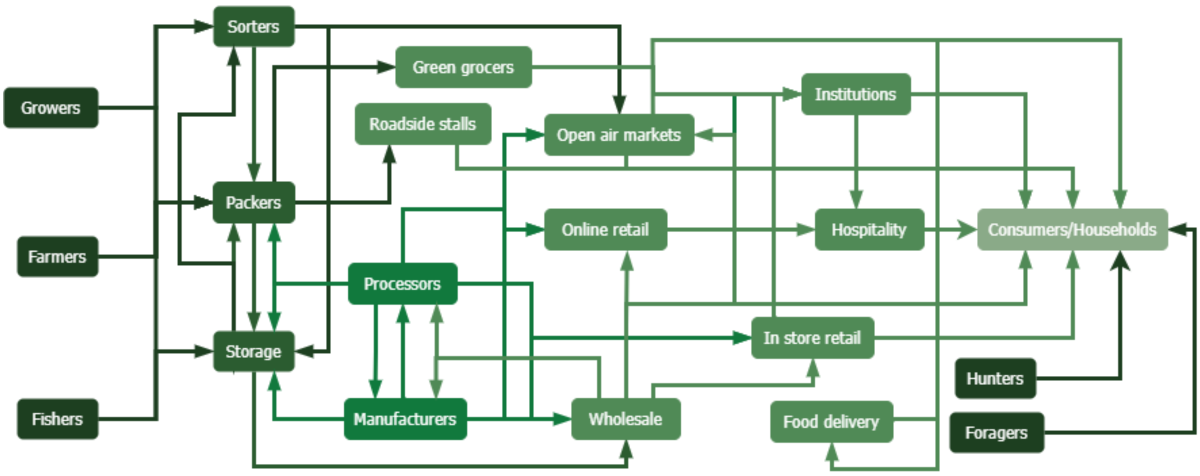


Figure 3: A detailed view of the food supply chain. Arrows indicate the movement of food along the chain. Darker colours indicate upstream and lighter colours indicate downstream.

This report is structured around the simplified model of the food supply chain. Section 3 looks at food loss during production; section 4 focuses on food loss in processing and manufacturing; section 5 examines food waste in retail and food service as well as wholesale; and section 6 considers food waste in households.

We precede these stage-specific examinations by taking a systems view in section 2. A systems view gives us a better understanding of the causes of and possible solutions to FLW.[9-11] This is because such a view shows where there are interdependencies, synergies, and trade-offs and illuminates ‘hidden’ drivers of FLW or barriers to change.[11,12] Section 2 also considers issues that affect FLW in all parts of the supply chain like transport and logistics.

In each of the following five sections, we describe what we know about FLW at each stage of the food supply chain and identify ways to prevent FLW on the basis of this information. What we know about FLW is uneven. We have drawn on many outstanding pieces of research from Aotearoa and abroad that give us deep insight into specific issues. Yet there are important gaps: we are unable to estimate with any confidence how much FLW is occurring at various points in the supply chain in New Zealand. A forthcoming baseline measurement, commissioned by the Ministry for the Environment (MfE), will provide information on FLW around Aotearoa; however, discussions with the team producing the report at the University of Otago (UoO) suggest that some gaps in data have been identified.

…we are unable to estimate with any confidence how much FLW is occurring at various points in the supply chain in New Zealand.

There is significant academic and grey literature on FLW in the supply chain, which we review throughout the report. At a high-level, in common with other supply chains, the food supply chain faces challenges in coordination, logistics, and matching supply to demand.[8] In the food supply chain, these challenges are exacerbated by perishability and food safety considerations.[8]

1.3 Food supply chains are both global and local

In Aotearoa, our food supply chains are globally connected. There is some food that is grown here and then exported (for example, premium grade kiwifruit and apples); food that is produced elsewhere and then imported (for example, processed products like some chocolate); food in which the entire supply chain is in New Zealand (for example, fresh lettuce); and food which is exported as raw ingredients and imported processed (for example, some brands of oat milk[*]). Case study 1 uses tomatoes to demonstrate the complexity of importing and exporting pathways for our food.

Case study 1: Tomatoes

Tomatoes are one of the most popular forms of produce in New Zealand.[13] Around the world, tomatoes are widely eaten in many forms including fresh, processed into pastes, preserves, purees, soup, and sauces, as an ingredient in other processed foods (for example, curries, frozen pizzas), and cooked in dishes prepared in food service or by consumers. The tomato industry is global and interconnected, many stages and stakeholders are involved to deliver tomatoes and tomato-based products around the world. Tomato production is one of the most advanced and globalised horticultural industries. China, India, Turkey, and the US (California) are the largest tomato producers, and many of these and other countries grow tomatoes in open fields. However, large-scale greenhouse growing is gaining in popularity and occurs globally, particularly in Europe, for intensified tomato production.[14]

As of 2023, Tomatoes New Zealand reported 140 registered growers of fresh tomatoes.[15] Growers choose varieties based on factors such as appearance, colour, texture, and flavour, as well as intended use and resistance to pests. The most popular varieties are vine, cherry, plum, and Roma (see figure 4).[16] Tomatoes are typically grown year round in greenhouses with soil-

[*] Although a factory is being built in New Zealand so that processing will eventually be domestic.

less hydroponic or semi-hydroponic systems for total environment control, increased yield, reduction in disease, and consistent quality. Greenhouse production is primarily around Auckland, the central North Island, Nelson, and Christchurch, with some open field production in Northland.[17] Locally based greenhouse crops are also a key part of food resilience to climate change and extreme weather events.[18]

Figure 4: Tomato varieties. Image credit: Eric Rautenbach (via iStock).

Tomatoes are mainly grown for the domestic market in Aotearoa, but around 10% are exported, predominantly to countries in Asia and the Pacific, with 41% of exports sent to Japan in 2023.[15,19] Fresh tomatoes currently can only be imported from Australia and must be irradiated to reduce the likelihood of fruit fly eggs or larvae – as well as be labelled as irradiated for consumer information. In 2023, 530 tonnes of fresh tomatoes were imported, compared to the 681 tonnes exported the same year.[15] Imports have been significantly lower than prior to 2012 (approximately 1,181 tonnes in 2011 and 3,085 tonnes in 2009) since the use of dimethoate (a treatment for fruit flies) was banned.[15] Exports have also decreased over the recent years (approximately 3320 tonnes exported in 2019) due to a pepino mosaic virus (known as PepMV) outbreak in 2021, as well as disruptions to sea freight, with growers not being able to export to the Australian market, resulting in an oversupply in the domestic market and reduced prices.[19]

Harvesting is done manually for fresh tomatoes grown in greenhouses, but in open field growing, typically for process tomatoes, harvesting is aided by machines.[14,20] Sorting and grading also takes place to remove damaged or diseased specimens and sort for size, colour and ripeness, for consistency and quality. Tomatoes are then packaged in crates or cartons and transported to processors, wholesalers, or retailers in temperature controlled trucks. The appropriate temperature depends on whether the tomatoes need to be ripened or stored.[21]

Figure 5: Canned tomatoes. Image credit: Brent Hofacker (via Adobe Stock).

'Process' tomatoes in New Zealand, which are used for canning (see figure 5) and tomato paste, are grown mainly in the Hawkes Bay and Gisborne.[17] Processing involves washing, blanching, peeling and cooking or combining tomatoes with other ingredients to turn whole tomatoes into a variety of products.[22] New Zealand imports processed tomatoes from Italy (47%), China (19%), the US (19%) and Australia (6%) and exports processed tomatoes to Australia (50%), Japan (34%) and Fiji (7%).[23]

During processing, large quantities of by-product consisting of peels, seeds and pulp are generated, known as tomato pomace (see figure 6). Up to 30% of the tomato may be discarded and is typically sent to animal feed, compost, or landfill.[24] However, efforts at higher levels of the hierarchy to reduce FLW including upcycling and valorisation through the creation of new products or biofuels is taking place.[24] Tomato pomace contains fibres, oils, lycopene, and proteins and has been used in powder form as a nutritional and antioxidant additive to foods such as baked goods, meat products, dairy products, and oil products.[25,26]

Figure 6: Tomato pomace. Image credit: Premium pet foods.[27]

Imperfect, misshapen, or damaged tomatoes are also typically lost or wasted especially if they are being sold fresh. There are a handful of companies such as Perfectly Imperfect[28] and Wonky Box[29] which sell vegetable boxes to customers that include some of these misshapen tomatoes (see figure 7).

Unsold fresh tomatoes in supermarkets may be donated to local food rescue charities and food banks or, if not fit for human consumption, be used for animal feed or compost.[30] The UK supermarket, Waitrose, began selling packs of mixed tomatoes that naturally fell off the vine or are misshapen as early as 2014 in an effort to reduce FLW.[31] Retailers can also provide information around handling, recipes, storage, and origin stories for consumer education. The average household likely has several fresh tomatoes or processed tomato-based products in their fridge or pantry and need to be able to make informed decisions around considerations such as ingredients, safety, portions, and quality regarding their food.

In Aotearoa, the upcycled food company Rescued has partnered with tomato producers including Heirloomacy and NZ Hothouse.[32,33] These relationships allow tomatoes that don't meet product specifications (see section 2.1.2) to be used in various processed forms, including supplying over 11 tonnes of tomato sauce to a catering company.[32,33]

Figure 7: Imperfect, misshapen or damaged tomatoes may be lost or wasted, though this can be prevented. Image credit: Katsiaryna Voitsik (via iStock).

1.3.1 Food export is a central part of New Zealand's economy

While Aotearoa is both an importer and exporter of food, it is food export that dominates our economy. As a nation, we export enough food to meet the energy requirements of 20 million people.[34] Figure 8 shows the value of our food and non-food exports since 1985. At the start of the series, food accounted for about half of the value of our exports. This has increased over time, with food accounting for 68% of the value of our exports in 2023, worth about $48 billion.[35]

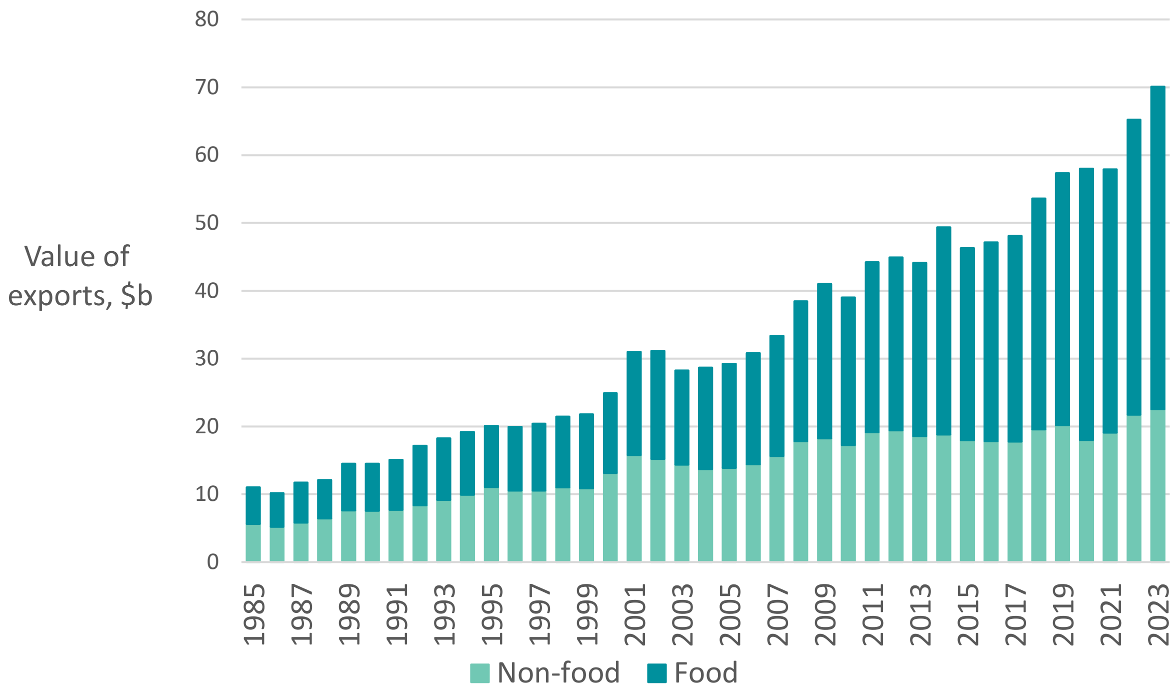


Figure 8: Value of food and non-food exports over time. The values are not adjusted for inflation. Data source: Stats NZ.[35] Abbreviation: b = billion.

Although we are diversifying, it seems likely that food export will remain an important pillar of our economy for the medium- to long-term. Because we are a small country, access to global markets provides opportunities not available domestically for our producers, processors, and manufacturers. The Government's expectations of the continuing importance of this sector is further signalled by the Ministry for Primary Industries'(MPI) choice of food export as the topic of their Long-term Insights Briefing (LTIB), focusing on consumer demand to 2050.

New Zealand has long sought to portray itself as environmentally friendly, with the country employing branding like "clean, green" and "100% Pure New Zealand".[36] In food exports, we have been proactive in highlighting our low impact production, actively countering narratives about the environmental harms of food miles.[37] MPI's LTIB suggests that this will become increasingly important because by 2050, the global consumers whom exporters in Aotearoa will be targeting will be highly aware of sustainability, which will influence their purchasing decisions.[38]

The primary sector has already started producing strategic work around sustainability.[39] The importance of exporting to our economy and the increasing expectations global customers have for sustainability makes it relevant to our continued prosperity that we are successful in our efforts to prevent FLW.

1.4 Reshaping the food system

In *Food waste: A global and local problem*, we described the social, economic, and environmental consequences of wasted food, including emissions and land and water use. However, the food system affects society in myriad other ways. The food system also provides livelihoods to tens of thousands of employees and small business owners in Aotearoa, employing one in five working people.[40]

Domestically, our food system has challenges. For example, one estimate suggests 21.3% of New Zealand children live in households reporting that food runs out sometimes or often.[41] Industrial agriculture, especially animal products, is associated with climate-changing emissions.[42,43] Proliferation of some types of processed foods may contribute to environments that promote obesity.[44]

We are cognisant that actions to prevent FLW may have broader impacts – positive or negative – in some of these areas. Preventing FLW is not just valuable in and of itself, but can play a role in improving the wider food system's outcomes. In a submission to the Commerce Commission, the industry body Horticulture New Zealand (HortNZ) noted that in recent years consumers have faced increasing prices at the same time as the amount growers earn for their produce has declined.[45] It is important to ensure that interventions to prevent FLW work to solve rather than exacerbate existing problems in the wider food system.

We lay out the alternatives and an assessment of the likely effects on FLW and some other food system outcomes, here and in our final report *Food loss and waste in Aotearoa New Zealand: Towards a 50% reduction*.

2. Looking across the whole supply chain

One approach to preventing FLW in food supply chains has been to measure and reduce waste at the various stages.*[,46] Thinking of the problem in discrete stages is useful, but masks a lot:

- The root causes of FLW are often complex and interconnected. They are also often in a different part of the supply chain to where the FLW occurs. One example is growers leaving produce unharvested, or tilling it back into the soil, because the cost of sending the produce to the next stage of the supply chain exceeds the expected returns.[47]
- Relatedly, the causes of FLW along supply chains are interrelated[48] and FLW can cascade across the supply chain.[49] Conversely, actions taken to prevent FLW at one part of the supply chain may have positive impacts elsewhere in the chain.[50]
- The different parts of the supply chain are often bound together and subject to many of the same challenges, including extreme weather, inadequate infrastructure, and labour shortages, as well as the same opportunities as new technologies emerge.
- Thinking in terms of the supply chain, rather than its constituent parts, allows a more holistic picture to form. This is particularly useful for measurement and monitoring, where assembly of fragmented data may tell a different story than would have emerged with system-level data.

The root causes of FLW are often complex and … in a different part of the supply chain to where the FLW occurs.

Our strong exporting orientation creates challenges and opportunities

Many New Zealand food businesses stand to make greater profits as exporters, because of the relatively small domestic consumer base. This creates economic incentives to produce as much as possible. Prevention strategies focusing on overproduction will therefore have limited effectiveness when much of the domestic production is targeting international markets. Further, the economic incentive to export premium produce creates a supply of produce that does not meet export grade, with its own FLW challenges. That is not to say the economic incentives are inherently at odds with preventing FLW: simulation modelling based on UK FLW data suggests the value of exports increase as FLW is reduced.[49]

FLW can arise because of disruption to export pathways. Disruption can be because of events beyond our borders; as a geographically isolated country we are reliant on global supply chains to transport our exports to their sometimes-distant end markets. In recent years, disruptions to global supply chains have been caused by the COVID-19 pandemic, a ship getting stuck in the Suez Canal, and a shortage of shipping containers. Domestic events can also disrupt export pathways; for example, Cyclone Gabrielle damaged crops so they failed to meet export quality specifications.

FLW can also arise from the uncertainties associated with exporting. In addition to the uncertainties around yield and quality faced by all producers, our exporters face uncertainty from competing

* We have intentionally prioritised a system view of the supply chain first, to emphasise the need for a systems approach to meaningfully prevent FLW. However, those who may be unfamiliar with the food supply chain components can jump ahead to read about each stage in sections 3-6 and then return to this section.

export markets – a glut elsewhere in the world will increase global supply, making export markets more competitive and potentially resulting in food failing to be exported.[51]

Food that cannot be exported is at risk of becoming FLW if it cannot be absorbed into the domestic food system. However, there are barriers to diverting food intended for export to the domestic market. Economic factors are one consideration: increasing the supply of produce to the domestic market decreases domestic prices at the same time as producers are going without the premium prices their products would have attracted in the international market.[52]

Our export orientation may create additional mechanisms for preventing FLW. The New Zealand-European Union Free Trade Agreement creates a platform for cooperation between Aotearoa and the EU on sustainable food systems.[53] This inclusion is the first of its kind and reflects the EU's focus on sustainability in trade and growth.[54] Among the topics covered is FLW with a view to achieving Sustainable Development Goal (SDG) 12.3. While the chapter of the agreement covering sustainable food systems has few specific actions, its inclusion is a signal that sustainability goals are being considered alongside economic ones in export markets. Moreover, it provides a mechanism for Aotearoa to benefit from progress made on FLW by EU researchers. As New Zealand pursues future free trade agreements for the benefit of our exporters, it may be worth exploring whether they could be a vehicle for further progress on FLW.

There are potential gaps in our knowledge around FLW in the domestic part of the export supply chain. The academic and grey literature has little to say about whether different strategies are needed to prevent FLW in domestic versus export supply chains. Additionally, we don’t have data to form a sense of the scale of the problem in export supply chains.

2.1 The drivers of food loss and waste across the chain

Box 1: Drivers, causes, and reasons

Much of this report attempts to unpick the ‘why’ of FLW. By identifying the ‘why’, we can identify opportunities for change that could reduce FLW. We talk about the ‘why’ in various ways. Largely we use 'drivers' and 'causes' interchangeably, which are those identified by experts in the research literature and in the sector. Where there are competing views on causality, we make this clear.

In a system as complex as the food supply chain, attributing causality is not straightforward. Sometimes, there might be a simple and direct cause and effect: a household bought more food than they needed and so some food was uneaten and went to waste. Often, however, the causes might be indirect: a supermarket promotion led to a household buying more food than they needed and so some food was uneaten and went to waste. At times, the pathway from the cause to the waste may depend on other factors: a supermarket promotion led to two households buying more food than they needed, and in one household food was uneaten and went to waste while in the other it was cooked and frozen for future use. The number of mediating steps and opportunities for different outcomes from the same starting point increase as the supply chain lengthens.

Conventional wisdom suggests that the bulk of FLW, at least in high income countries like New Zealand, comes from consumers discarding food that is still good to eat.[55] Businesses are generally incentivised to maximise profits,[56] and minimise waste. However, we know in Australia – which is likely to be fairly comparable to Aotearoa – only 32% of FLW happens in households.[57] A narrow focus on consumers, neglecting the commercial supply chain, will be ineffective. It also suggests that individual consumers are responsible for the problem, when they have much less influence than large commercial actors. Nonetheless, collective consumer awareness and purchasing power can drive change.[58] We discuss consumers in detail in section 6.

…collective consumer awareness and purchasing power can drive change.

The loss of food along the supply chain provides insight into the operations of the food supply chain: it can be more profitable to individual actors to let food exit the chain than to keep it in. For example, growers may find it more profitable not to flood the market with a crop that is in season, which might lower the price. This is especially apparent in production, where, for example, labour costs to harvest fruit can be up to two thirds of all input costs, making it economically unviable to harvest.[51]

In this section, we explore drivers of waste across the supply chain (see box 1). We modify thinking that emerged from a New Zealand case study in the kiwifruit industry, which identified two competing framings of the causes of loss in the sector: the first framing is that loss in the sector was driven by technical or operational failings and was described as 'supply chain driven'; in contrast, the second framing sees loss as the result of market driven quality specifications, where loss is an inevitable corollary of value.[47] We expand the scope of 'market driven' loss to include the power relationships between parties in the supply chain. We use 'supply chain driven' and 'market driven' as competing framings of the problem, we use them to categorise specific drivers of FLW that emerge from our evidence review and stakeholder engagement. Many of the drivers outlined in this section are explored in more detail in the rest of report in relation to specific supply chain stages.

2.1.1 Supply chain driven

Difficulty forecasting demand

A key driver of FLW across supply chains in high income counties like Aotearoa is overproduction; that is, more food being produced than will ultimately be consumed locally or exported. Some of this overproduction is market driven, which we discuss later in this section. But some overproduction arises from difficulty in accurately anticipating the amount of food needed. The challenge of demand forecasting is widely agreed to be an important driver of FLW across the supply chain.[59,60,61]

Demand forecasting is challenging for a number of reasons. In the case of primary production, there is a lag time between when decisions are made that will determine production levels – for example, the size of herds, mix of crops, and the number of workers – and when demand is confirmed by contracts with upstream actors.[45] Further downstream in retail and hospitality, demand fluctuates quickly and often unpredictably, for example, around weather or local events.

Demand forecasting is made more challenging because of data siloing across the supply chain. Although data sharing could enable all supply chain actors to have more accurate demand forecasts, a mix of logistical challenges, such as data not being interoperable, the existence of relatively few tools for sharing data, and concerns around competitive advantage, mean this often does not happen.[62,63]

Logistics

Significant planning is needed for food to move from production along the supply chain to where it is consumed. Among the considerations are: having suitable transport and storage available at the right times; ensuring all the components of a manufactured product or a food service menu are available at the same time; coordinating the use of machinery used for multiple products; and optimising stock levels. A 2021 literature review identified 49 studies that described logistics-related drivers of FLW across five categories: transport, warehousing, inventory management, packaging, and communication.[64]

Breakdowns in logistics create conditions that promote FLW. Delays in transportation to perishable food use up more of its shelf life before it reaches its final destination, making it more likely to be discarded without being consumed.[48,59] Failure to maintain proper temperature control can lead to FLW by shortening the shelf life of fresh produce, or by introducing food safety risks that require disposal.[65]

The contribution of suboptimal logistics to FLW in Aotearoa is unclear, with a lack of available data. Globally, Boston Consulting Group (BCG) estimates that of US$700 billion of FLW that could be prevented each year, about US$270 billion could come from improvements to supply chain efficiency and infrastructure.[60] It is unlikely that such a high proportion of preventable FLW in New Zealand is due to logistics as BCG's global estimate will include low income countries. In the US, ReFED estimates that "enhanced product distribution" would avert about 1.7 million tonnes of lost and wasted food.[66] In Australia, 423,000 tonnes of food is lost or wasted in transport and distribution.[65]

…of US$700 billion of FLW that could be prevented each year, about US$270 billion could come from improvements to supply chain efficiency and infrastructure.

The human element

In a study of the Portuguese food supply chain, researchers identified pathways through which human error can drive FLW.[48] These included: rough handling of products leading to physical damage and making products more vulnerable to microbial damage; storage at the wrong temperature leading to either physical damage or risk of food safety issues; and storage and inventory management decisions that shorten items' shelf life or do not make them available to move along the chain within their shelf life.[48] We did not find any systematic data on the role of human error in the New Zealand food supply chain, although human decision making has been identified as a factor in the New Zealand retail sector.[67] In our stakeholder engagements, human error was often mentioned as a cause of FLW, albeit of varying significance according to different stakeholders.

In Australia, 423,000 tonnes of food is lost or wasted in transport and distribution.

The human element also comes in through stakeholder attitudes, which can affect inclination to undertake sustainable approaches to FLW.[68] The human element is particularly relevant to household food waste, which we discuss in section 6.

Data gaps

Data is a key component of FLW prevention.[50] As we have highlighted in our previous reports, there are gaps in FLW data in New Zealand. Sections 3, 4, 5 and 6 will describe available data and data gaps at each stage of the supply chain. But the supply chain is a complex system rather than a series of independent stages, and data needs to be captured in a way that supports optimisation of the system as a whole. At the supply chain level, data is important to prevent FLW in two ways. Firstly, to identify 'hotspots'[69] for targeting, and secondly, so that the effects of actions taken at one part of the supply chain on FLW elsewhere can be detected. The forthcoming baseline measurement does take a systems perspective, which will be a valuable contribution to the data landscape.

However, data gaps will remain. There are parts of the supply chain where data was unavailable for the research. Moreover, while the forthcoming baseline measurement is an important milestone for New Zealand's progress towards SDG 12.3, further advancement is needed in data collection and reporting. Most obviously, the baseline uses secondary data sources, which are difficult to compare because of differences in the data collection methods. Moreover, the baseline is a snapshot of a single point in time. Longitudinal data is needed to monitor progress towards SDG 12.3 and the success of policies aimed at reducing FLW. Additionally, the Food and Agriculture Organization of the UN (FAO) suggests that data should capture not only the magnitude of the FLW and where in the supply chain it occurred, but also the underlying causes and drivers.[70]

Data on topics other than FLW itself also has relevance. For example, understanding the degree of digitalisation in the supply chain would be useful. Data gaps here exist because downstream players are characterised generally as, for example, wholesalers, retailers, transport, which includes these types of businesses from non-food sectors; therefore, it isn't possible to look at food supply chains in isolation. More data is available upstream where agriculture is its own category, although this may also be too coarse a category to be useful.

A centrally commissioned research survey is not the only way to meet our data needs. We discuss how supply chain actors can use and share their own data in section 2.2.2, and barriers to them doing so in section 2.3.5.

2.1.2 Market driven

Terms of trade

The movement of food along the supply chain is governed by contracts between the various parties. The terms of these contracts incentivise overproduction, with purchasers often exerting their greater power so that a supplier’s failure to supply enough product would be economically damaging to them. Meanwhile, the costs – both economic and the waste produced – of overproduction also lie with suppliers. We discuss this with regard to the retail sector's ordering practices in section 5.2.2.

One example of trade arrangements that cause FLW is ‘take-back’ agreements.* These contracts are common internationally for the supply of bread to larger retailers like supermarkets. They are structured so that retailers do not pay for the quantity of bread ordered, only the quantity sold, with the supplier responsible for the costs of disposing of any unsold product.[71] A Swedish case study found that up to 30% of bread ordered between 2011 and 2015 was returned.[72] Our attempts to understand the role of take-back agreements in New Zealand's bread industry were hampered by confidentiality agreements for some of our key stakeholders. However, a premium Auckland baker describes the process of supplying supermarkets in a way that is consistent with a take-back agreement.[73] Additionally, public-facing communications from the industry talk about ‘returns’.[74,75] For one large bread manufacturer, roughly 10% of products are returned.[74] In total, one estimate puts the annual bread ‘returned’ to New Zealand manufacturers at nearly 10,000 tonnes.[75] Demand for the donation of bread in Aotearoa is limited so much of this ends up in landfill.

A Swedish case study found that up to 30% of bread ordered between 2011 and 2015 was returned.

Quality specifications

Food must meet quality specifications to progress along the supply chain. Specifications exists for

* Also known as 'sale and return' and 'scan based' agreements.

multiple reasons. Some are pragmatic, for example, size and shape requirements to facilitate packing and transport. Others relate to the eating experience, for example, an acceptable range of sugar concentration. Specifications also include cosmetic issues, like size, shape, (cosmetic requirements for size and shape are distinct from size and shape requirements for packing and transport reasons) or colour. For produce especially, cosmetic specifications can appear arbitrary and result in edible food being lost. More details on how such specifications contribute to FLW are described in sections 3, 4, and 5. This issue's appearance in multiple sections of this report reflects its complexity.

The underlying reasons for cosmetic specifications leading to food being lost and wasted are contested, with one argument being that the supply chain is simply responding to consumer demand and the other being that consumer preferences are learned and responsive to both what is available and evidence-based communications campaigns. Box 2 explores how specifications are set in more detail.

Box 2: Who sets cosmetic specifications for food products?

Cosmetic specifications,[*] which dictate the acceptable appearance of fruits, vegetables, and other food items, are considered an important driver of FLW throughout the supply chain.[76] The responsibility for these specifications is complex, as various actors along the supply chain influence the criteria that dictate the way our food looks. Retailers are at the forefront of setting cosmetic specifications, enforcing the criteria for the size, shape, and colour of produce to meet the demands of customer preferences[76] and maximise the appeal of products on their shelves. Consumer expectations and preferences play a significant role in the perpetuation of cosmetic specifications, as their purchasing patterns create demand for cosmetically perfect produce. However, it's important to note that consumer attitudes are learned and in part shaped by what's available to them in retail settings,[77] creating a feedback loop that reinforces stringent cosmetic specifications. There is some evidence that consumer acceptance and purchasing behaviours based on appearance, size, and weight are malleable. Research on children's perspectives has shown that recurring exposure through seeing, using, and consuming 'ugly' fruit and vegetables leads to greater acceptance,[78] and that targeted marketing and socialising of 'different' or non-uniform produce improves purchasing frequencies.[79]

Cosmetic specifications can also be used by retailers as a tool to respond to supply and demand, as illustrated by the relaxation of cosmetic quality during times of short supply.[80] In order to sell their produce, farmers and producers have to reactively adapt to the specifications set by retailers and market demands, and, in doing so, can further entrench cosmetic specifications by selecting and cultivating crop varieties that are more likely to meet retail and consumer expectations.[76] Additionally, some cosmetic specifications may by influenced by industry bodies, national or international regulatory bodies, and certification agencies, which can relate to quality, safety, and trade specifications. This is particularly relevant in New Zealand's export oriented production sector (see section 1.3). While some regulations like the Overseas Market Access Requirements are in place to ensure food safety and export acceptance, they can indirectly contribute to establishing cosmetic norms in food production, and in turn FLW.

2.2 Potential solutions

We have identified a number of potential solutions to the supply chain level drivers of FLW. These solutions are described in detail in the remainder of this section, and table 1 summarises the drivers each solution addresses, as well as related recommendations. Additional solutions or applications of

[*] Note, cosmetic specifications do not include standards or specifications that pertain to food safety.

these solutions that affect particular stages of the supply chain are presented in the relevant sections later in this report.

Table 1: Potential solutions to prevent food loss and waste and the drivers they address. Abbreviations: FLW = food loss and waste, SAP = sector action plan.

Solution	Driver(s) addressed	Related recommendation(s)
Research and innovation.	• Logistics. • The human element. • Data gaps. • Quality specifications.	P8: Pursue opportunities to reduce FLW through research and innovation.
Digitalisation of the supply chain.	• Difficulty forecasting demand. • Logistics. • The human element. • Data gaps.	P3: Support the creation and adoption of a data platform for the sector.
Shifting practice across the supply chain and at home.	• The human element.	P1: Utilise SAPs to identify intervention opportunities that take a systems view while allowing for the unique contexts of different sectors. P7: Continue to explore alternatives to traditional date labelling. P9: Support evidence-based consumer communications campaigns.
Finding ways to keep imperfect produce in the supply chain.	• Terms of trade. • Quality specifications.	P4: Encourage novel and emergent models of food purchase by consumers. P5: Identify mechanisms to avoid FLW caused by extreme weather events. P6: Update specification practices that lead to edible food being discarded.
Changes to purchasing agreement structures.	• Terms of trade.	P1: Utilise SAPs to identify intervention opportunities that take a systems view while allowing for the unique contexts of different sectors. P2: Evaluate the effect of the Grocery Supply Code on trade term driven FLW.
Collaboration.	• Logistics. • Data gaps. • Terms of trade.	P1: Utilise SAPs to identify intervention opportunities that take a systems view while allowing for the unique contexts of different sectors. P5: Identify mechanisms to avoid FLW caused by extreme weather events.

2.2.1 Research and innovation

Research and innovation has significant scope to prevent FLW. Specific applications at different stages of the supply chain are highlighted throughout the report, including case study 8, case study 10, and annex 1. Broadly, relevant research and innovation applications include innovating around the food itself, for example, breeding for specific traits; genetic editing (subject to legislative changes); and product formulation; innovation around the way people interact with food, for example, creation of new tools and packaging technology; and digital technologies (which we discuss in section 2.2.2 and which has some overlap with innovations that change our interactions with food).

Harnessing research and innovation relies upon a suitably resourced research sector and close alignment between research agendas and the needs of businesses along the supply chain in Aotearoa. These needs include not only discrete problems that a new technology could solve, but also support with implementation across the supply chain. We explore research and innovation in more detail in section 7.

2.2.2 Digitalisation of the supply chain

A fully digitalised and integrated supply chain opens multiple opportunities to address FLW, including improving demand forecasting and logistics and reducing human error (see section 2.1.1). A detailed list of relevant digitalisation applications appears in table 7; some relevant elements of a fully digitalised supply chain are:

- Devices connected to the Internet of Things (IoT), for example, sensors that can allow monitoring of food in its journey across the supply chain. Sensors already exist to optimise growing and harvesting and time of slaughter decision making,[81] and to monitor conditions like temperature and humidity of food as it travels along the supply chain.[82] The information recorded in sensors can be reported to a human for action, or can automatically adjust systems such as temperature control using artificial intelligence (AI) or preprogrammed conditions. A fully digitalised and integrated supply chain with these features could prevent FLW through multiple pathways. Sensor technology can both prevent reduction in shelf life by creating an alert to avoid improper handling or storage, and enable accurate assessment of reduced shelf life arising from improper handling and storage to be a part of inventory management decisions.[83]
- Distributed ledger technologies (see box 5) like blockchain ensure that all parties have access to the same information at the same time, for example, about the location of a given pallet as it moves within a warehouse or from a manufacturer to a retailer.[84] Blockchain potentially enables better coordination across the supply chain, for example, by ensuring a retailer is ready to receive a delivery at the right time; it also improves traceability.[85] Walmart in the US has integrated blockchain into its procurement.[84] Distributed ledger technologies can prevent FLW by, among other things, allowing precise targeting of recalls.[86]
- A digitalised supply chain collects an abundance of data. With appropriate analytics, this data can offer insight that could improve the operation of the supply chain. 'Big data' approaches are well-suited to this kind of challenge, and AI could be useful when data is of different types and stored in different modes across the supply chain. Demand forecasting can also be improved with more sophisticated analytics.
- Data stored on a suitable platform can be shared appropriately allowing relevant stakeholders to access, analyse, and visualise the data without compromising commercially sensitive matters.
- Digitalisation allows greater automation, which can in turn prevent FLW caused by human error.

While various tools enabled by digitalisation have potential in preventing FLW within organisations, at the supply chain level, data sharing across the chain is essential. Shared data would allow upstream players to modify their operations in response to demand forecasts downstream. Analytics drawing on data from across the supply chain can identify hotspots in FLW, for example, specific ingredients that are overproduced. Gains in efficiency in logistics from digitalisation rely on data flowing across the chain. A platform facilitating this data sharing would enable integrated supply chain management which has been identified by researchers as a key leverage point for prevention.[87]

While various tools enabled by digitalisation have potential in preventing FLW within organisations, at the supply chain level, data sharing across the chain is essential.

Internationally, governments at various levels are pursuing the creation of such platforms for sharing and analysing data. The EU has outlined plans for creating common data spaces for a range of sectors and topics, including agriculture and also for their 'green deal'.[88] Various projects developing agricultural data spaces have been funded by the Horizon Europe programme, of which New Zealand is now an associate member.[89-92] In Aotearoa, Trust Alliance New Zealand, a non-profit industry consortium, is creating a platform for farmers to share data through a digital wallet, which may be a useful model in designing a data platform for sharing data across the supply chain to improve logistics.[93] To our knowledge, there is not as yet a platform spanning the whole supply chain.

A platform for sharing data has value for efforts to address FLW at many levels of the hierarchy, not just prevention. Similarly, a data sharing platform could benefit other food system outcomes like nutrition, food security, and local food business viability.

2.2.3 Shifting practice across the supply chain and in households

While not strictly part of the supply chain, consumers are a significant contributor to FLW. We discuss strategies to address household food waste in section 6.2.

Within the supply chain, improving employee practice has the potential to avert FLW. In Australia, Food Innovation Australia (FIAL) estimates that providing training around best practice to employees across the food supply chain could avert more than 265,000 tonnes if undertaken only by industry, or more than 325,000 tonnes if undertaken by industry and policy makers in combination.[57]

There are a variety of models this could take. End Food Waste Australia's (EFWA) sector action plan (SAP) for the bread and bakery sector includes development of a guide for best practice and a toolkit for waste prevention, and the creation of micro-credentials around reducing FLW in the sector.[69] As described above, digitalisation of the supply chain offers opportunities to reduce or mitigate human error, as does automation of processes.

More generally, organisational culture has a role to play. There is evidence that organisational culture may affect employees' motivation and attitudes,[94,95] and this in turn is related to employee and organisational performance.[95] Importantly, the relationship between organisational culture on the one hand, and organisational and employee performance and behavioural outcomes on the other, has been found not only for organisations' core business but for dimensions such as ethical[96] and environmental[97] behaviours. Interventions to raise awareness and change practice should be targeted not only at employees but also at leaders within organisations. More specifically, this could involve a combination of bottom-up culture change initiatives and top-down accountabilities for the organisational sustainability profile and leadership teams.

The success of communication led interventions to target organisational culture change may be low, especially for small and medium enterprises (SMEs), if there is not seen to be a benefit to business performance.[98] It has been suggested that SMEs are more likely to alter their behaviour when the issue is one of compliance,[98] and there are models where regulation has affected business culture and practice, such as health and safety.[99] However, such regulation may create unreasonable compliance burdens for SMEs.

2.2.4 Finding ways to keep 'imperfect' produce in the supply chain

One approach to reducing FLW arising from cosmetic specifications would be to simply widen those specifications. This is only likely to be possible for domestic, non-premium products. However, for this to actually prevent FLW, rather than simply moving the location of the FLW further down the supply chain, the produce captured by such a relaxation would have to be purchased by consumers.

The evidence is contradictory on whether this is likely to happen. On the one hand, New Zealand consumers have shown themselves willing to purchase 'imperfect' produce, as demonstrated by the success of Odd Bunch[100] and Wonky Box.[29] The success of lines like Odd Bunch suggests that consumers are willing to buy food explicitly branded as imperfect and at risk of going to waste, while the success of adjusting acceptable sizes of potatoes suggests that some status quo settings aren't strongly tied to consumer preferences.[80] Additionally, there is a long history of marketing effectively employing behavioural science to influence consumer preferences and behaviour.[101] On the other hand, during our engagement, we heard that in the case of carrots, market research had found that consumers would accept a bag of carrots with a certain proportion of carrots that were misshapen, and any more than that proportion would be rejected. We also heard that even for frozen peas, a company that changed its specifications to accept yellow peas as well as green received negative feedback from its customers. These are observations based on anecdotes or confidential data, and this question would benefit from a rigorous analysis of systematic data sets, by sector. It is likely that any conclusions will be context dependent.

Consumer preferences are not fixed, and, as discussed in section 6.2.1, we have reasonable evidence about communication strategies that are effective in changing preferences and behaviours.[*] An evidence-based consumer communications campaign will be crucial to the success of any widening of specifications aimed at reducing FLW.

For any chosen specifications, there would still be produce that falls outside while being safe to eat (see figure 12). Preventing this produce falling down the hierarchy (to food rescue as described in *Food rescue in 2022: Where to from here?* and upcycling, animal feed, and material, nutrient, and energy recovery as described in *Beyond the bin: Capturing value from food loss and waste*) requires secondary markets for these products. Barriers to these secondary markets include fluctuating and not completely predictable supply, and a lack of flexibility in operations to switch between, for example, fresh and processed supply chains. These barriers may be reduced further down the supply chain as the scale generated from combining products from multiple individual producers could reduce uncertainty about supply and make it more economically viable to invest in parallel operations. In section 2.3.2 we discuss some of the barriers to trying to keep more imperfect produce in the supply chain.

Digitalisation of the supply chain (see section 2.2.2) could allow for a clearinghouse for produce failing to meet specifications – facilitating dynamic secondary markets and taking the burden off producers who don't have capacity to seek secondary markets for their produce. Woolworths Australia and BCG have developed such a clearinghouse, Refresh Food, a business-to-business platform for farmers to sell their excess produce.[102]

[*] While there is a broad literature on 'nudge' type methods to change behaviour, the degree to which such interventions are successful or appropriate is contested.

Based on our stakeholder engagement, a useful starting point to make progress in this space would be to review produce that is harvested but consistently becomes surplus, produce that goes unharvested if not purchased, and existing secondary markets. We also note the potential of upcycling as a destination for produce that doesn't meet specifications, which we discuss in more detail in our previous report *Beyond the bin: Capturing value from food loss and waste*.

2.2.5 Changes to purchasing agreement structures

Aotearoa is not alone in having purchasing agreements that fail to disincentivise waste. Take-back agreements for bread, for example, are common in Europe [71,72,103] and Australia.[104] Variation at short notice in both quantity and price of produce to be purchased is common in Germany and Italy.[105] The Grocery Supply Code (the Code) (see box 8) introduces a requirement for agreements to be in writing, but does not require that the agreement specify price or quantity.[106]

Although contracts that make it harder for upstream actors to avoid waste are common, they are not inevitable. One approach to addressing unfair terms is through legislation, as we have seen in New Zealand with (the Code). Narrower pieces of regulation can also be used to target specific practices – for example, in South Australia, bread take-back schemes are not permitted and the state produces less than half the amount of bread waste as other Australian states, with no evidence of higher prices.[104] However, take-back arrangements are recommended in some circumstances as a way to reduce FLW that arises from products with short shelf lives spending a lot of time in transit across the supply chain or in distribution centres.[107]

…in South Australia, bread take-back schemes are not permitted and the state produces less than half the amount of bread waste as other Australian states, with no evidence of higher prices.

One innovative purchasing agreement is whole crop purchasing, which, as the name suggests, involves purchase of a whole crop rather than only the segment of that crop that meets quality specifications.[*] Instead of intentionally creating food loss by growing a surplus to ensure they have enough product that is within specifications (and ploughing in crops outside of these specifications), producers are able to 'right-size' their crops. Purchasers are able to pay less per unit or weight of food because of the variable 'quality' while producers maintain their profitability because they can be paid for products that don't meet specifications. In a vertically integrated supply chain – as we have in Aotearoa (see section 5.1.1) – whole crop purchasing is viable because purchasers have the ability to use non-premium products in their own brand processed lines.[107]

Contracts could also cover longer time periods. This would provide greater certainty for suppliers, enabling planning and purchasing of large equipment – including FLW reducing technology.

2.2.6 Collaboration

Collaboration across the supply chain is necessary for FLW prevention for several reasons. The causes of FLW are not necessarily in the same part of the supply chain as the FLW occurs. Further, identifying drivers requires all levels of expertise, from policy through to production floor stakeholders. Collaboration can ensure that interventions genuinely prevent FLW, rather than simply pushing it to another part of the supply chain. Collaboration also facilitates complementarity and efficiency in prevention efforts. Despite the potential to reduce FLW – and for benefits in other domains – there are often barriers to collaboration.[108]

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[*] Quality specifications aren't inherently unfair trade practices, but they share many features with unfair trade practices that are relevant to FLW, namely, that loss is created to mitigate economic risk, which is unevenly spread between the contracting parties.

Internationally, FLW efforts have typically been industry led by a coalition of food sector companies, such as in Norway, Hungary, Spain, Germany, and the Netherlands, or third party organisations such as the Waste and Resources Action Programme (WRAP) in the UK, or Too Good To Go, which was started in Denmark but now operates across several EU countries as well as in North America.[109] In the UK, the Courtauld Commitment is a voluntary agreement including businesses across the supply chain.[110] Through the Courtauld Commitment, 315 food businesses have committed to the UK's Food Waste Reduction Roadmap, and 19% are described as "actively collaborating" with their supply chain partners to reduce FLW.[111] EFWA's Food Pact initiative[112] is another example of a voluntary agreement for industry organisations to measure and quantify FLW and FLW action, collaborate with each other and researchers, and apply innovative solutions across the supply chain. Government departments are also involved and EFWA's research projects and initiatives are on track to generate $2.7 billion in industry profitability by 2033.[113] New Zealand's own Kai Commitment[114] (see case study 2) is a version of this, with data being collected and shared (anonymously) across the food industry and collaborative practices across the sector being developed.

Internationally, FLW efforts have typically been industry led by a coalition of food sector companies… New Zealand's own Kai Commitment is a version of this, with data being collected and shared (anonymously) across the food industry and collaborative practices across the sector being developed.

One model of collaboration brings together stakeholders from across the supply chain to establish a unified plan of action for a sector as a whole. EFWA calls the output of this approach sector action plans (SAPs) and the Pacific Coast Collaborative in North America calls their analogous process 'sector summits'. Key strengths of this approach are diverse stakeholders and sector specific understanding of the problems.[115] The Australian SAPs follow a process of 'review-plan-do', with opportunities for key stakeholders to come together over multiple phases of the project.[116]

Actions proposed in SAPs generally fall in one of five categories: policy levers; research, development and extension; implementation; building a community of practice; and monitoring, evaluation, reporting, and improvement. In some domains, members of the SAP, along with other interested stakeholders, can immediately implement a recommended action. For example, one outcome of the bread and bakery SAP[69] was the development of a toolkit for bakeries offering practical guidance on how to reduce their waste,[117] which was launched at a national trade show in 2023. In other domains, the proposed action will take some time to happen: for example, monitoring waste across the dairy supply food chain is the subject of a current research proposal.[115] Outcomes of the Pacific Coast Collective's sector summits include consumer messaging in the food service sector, which improved consumer awareness of waste, and 'whole chain' projects that quantified waste across strawberry and potato supply chains.

…one outcome of the [Australian] bread and bakery SAP was the development of a toolkit for bakeries offering practical guidance on how to reduce their waste…

To our knowledge, New Zealand has no equivalent to SAPs or sector summits. Kai Commitment may fill some of this gap by providing a community of practice, but there are key differences. Firstly, outputs of SAPs are public facing and involve calls to action both inside and outside the sector, while the work of signatories to the Kai Commitment is generally kept confidential and are actions to be taken only by signatories. Secondly, SAPs bring together stakeholders from specific sectors, for example, the dairy industry, or cross-cutting areas, for example, cold chain stakeholders. This allows identification of the causes and solutions relevant to specific supply chains. Finally, SAPs can be used to identify drivers of solutions to FLW for the benefit of a wider set of stakeholders rather than just the participants involved, although this may not be the case in practice.

The Kai Commitment, the Australian Food Pact, the Pacific Coast Collaborative, the Courtauld Commitment, and SAPs are examples of formalised voluntary collaboration with the explicit purpose of addressing FLW, taking place outside of business as usual. These are not the only formats in which collaboration can impact FLW. Voluntary collaborative action can also be taken informally and on an ad hoc basis, as was the case when British supermarket Sainsbury's extended lamb season after poor weather delayed lamb growth.[118] This averted food loss, but the reasons given for this action by Sainsbury's were related to valuing their relationships with suppliers.

Case study 2: Kai Commitment

The Kai Commitment in New Zealand is an initiative of the New Zealand Food Waste Champions 12.3 Trust, aimed at reducing FLW by 2030 in line with SDG 12.3.[114] This multi-year programme involves a collaborative platform for businesses to maximise the value of the food they produce, distribute, and sell, by adopting sustainable practices. The programme is structured around a framework that encourages businesses to set targets for reducing FLW, measure their waste in a consistent manner, take action on reduction activities, and collaborate to share best practices and innovate in the field.[114]

Key participants in Kai Commitment include prominent New Zealand food businesses like Woolworths NZ, Foodstuffs NZ, Goodman Fielder, Fonterra, Silver Fern Farms, AS Wilcox, and George Weston Foods, along with Nestlé. These signatories have committed to targeting, measuring, and acting on FLW reduction. The initiative is supported by various partners and establishment supporters, including funding from MfE. Kai Commitment emphasises the importance of a collaborative approach to tackle the issue of FLW, recognising that this is a shared challenge that benefits from collective action and shared solutions across the supply chain. By bringing together different stakeholders in the food supply chain and facilitating the exchange of knowledge and best practices, Kai Commitment aims to create a more efficient, productive, and sustainable food system in Aotearoa (see figure 9).

Figure 9: The Kai Commitment launch event in Auckland, 2022.

2.2.7 Implications for policy settings

Policy settings can influence the drivers of FLW.[119] There are a number of general levers available, from explicitly banning or requiring certain actions, to providing or supporting enabling infrastructure, to incentivising action through tax and other financial mechanisms. We explore the following policy actions that could be taken by government as follows:

- Disincentivising disposal by banning food waste to landfill (section 4.2.3 and annex 2), and implementing 'pay as you throw' (see section 6.2.2).
- Reviewing date labelling requirements (see section 4.2.3 and box 9).
- Regulating against unfair trade practices (see box 8).
- Supporting research, innovation, and digitalisation (sections 3.2, 4.2, 5.2 and 7).
- Supporting school programmes (see section 6.2.1).
- Undertaking consumer communications campaigns (section 6.2.1, and annex 5).

2.3 Sticking points

Most actions to address FLW – and any reductions in FLW – affect different actors in the supply chain differently.[70] Producers, for example, could profit from reducing on farm loss because they would have either reduced input costs for the same amount of product or more product for the same input costs. On the other hand, retailers' profits would reduce if consumers wasted less food at home and purchased less food. A reduction in oversupply may result in less food being available for food rescue organisations to distribute, requiring more investment in food security and food system resilience.

Although a net benefit to reducing FLW is widely accepted,[70] not all businesses will immediately benefit from some prevention efforts. Additionally, even interventions that don't obviously create winners and losers may be more accessible or useful to some businesses than others. In the remainder of this section, we explore some of the ways experiences of prevention interventions may differ along the supply chain. In our recommendations these aspects are captured under 'considerations'.

2.3.1 There is an evidence gap

Although the academic and grey literatures suggest many interventions to address the drivers of FLW across the supply chain, few of these have been formally evaluated. Many proposed interventions have not been implemented or have been implemented very recently, providing little opportunity for evaluation; robust quantitative data of the type necessary for evaluation are scarce; and it is challenging to convincingly evaluate the impact of interventions that aim to contribute to system change.[120] The exception to this may be some behaviour change interventions targeting consumers, although this is still challenging (see section 6.2.1).

Modelling has also been undertaken to estimate how different scenarios would affect FLW.[49] The Australian National Food Waste Strategy used cost benefit analysis to prioritise potential interventions and identify their potential impact.[57]

Future interventions should be monitored and evaluated as rigorously as possible, to build an evidence base to inform system changes.

2.3.2 Relaxing quality specifications has potential benefits but would create new challenges

Much of the FLW that we attribute to quality specifications occurs because of financial incentives. Relaxed quality specifications and/or new secondary markets would need to change these incentives to be effective in preventing FLW. This may be challenging to achieve. For producers, the input costs are similar regardless of whether the product meets specifications or not. Conversely, consumers are willing to pay a premium for 'high-quality' products or expect to pay less for 'low-quality' products. Another consideration is that bringing more 'imperfect' foods to consumers could work in competition with secondary markets for these products.

Relaxing specifications as a solution to FLW assumes that items that do not meet current specifications, but would meet relaxed specifications, can be sold. Consumers might be persuaded to purchase such products (see section 2.1.2) but this needs to be confirmed to prevent food previously lost on farms being wasted in supermarkets instead.

Finally, it may be challenging to get some stakeholders onboard. Retailers or industry brands who position their products as premium may be legitimately concerned about the impact of relaxed specifications on brand image. Additionally, operational adjustments like extra sorting or modifications to packaging may be needed, and the price achieved for affected products would have to compensate for expenditure arising from these adjustments.

2.3.3 Voluntary agreements are voluntary

Businesses can only be expected to voluntarily engage in practices that prevent FLW if branding and reputational considerations outweigh the costs. In our stakeholder engagement, we heard that during a SAP process in Australia, one stakeholder withdrew because the recommended action would be detrimental to their business. Voluntary agreements can also be prohibitive to small businesses if the cost of joining is too high.

The limits of voluntary agreements are tested when collecting and monitoring FLW data. There is an increasing appetite internationally for employing mandatory reporting of FLW to enable fairer, more consistent, and robust reporting. Most recently, a coalition of over 30 major food businesses, including most major UK supermarkets, published an open letter to the UK Department for Environment, Food and Rural Affairs (DEFRA), urging legislation around mandatory reporting, resulting in DEFRA agreeing to reconsider ruling it out.[121,122] An important consideration when implementing mandatory FLW reporting is to build in recognition that drivers for FLW often lie elsewhere in the supply chain from where FLW occurs. Data collected and communicated from any mandatory reporting should be carefully designed to capture this.

…a coalition of over 30 major food businesses, including most major UK supermarkets, published an open letter to the UK Department for Environment, Food and Rural Affairs (DEFRA), urging legislation around mandatory reporting…

2.3.4 Adoption of innovation can be expensive and slow

Part of the solution to our FLW problems includes innovation. We highlight novel business models and technologies and how big data could make a difference throughout this report. However, not all players in our food supply chain are equally well positioned to take advantage of new technologies.

Most New Zealand businesses, including businesses in the food supply chain, are SMEs.[123] SMEs face particular challenges to adopting innovation within the business, as they often lack specialised human resources and costs can be prohibitive.[124] In addition, in our conversations with experts in the Aotearoa supply chains, we heard that the demands of business as usual may limit resources – human and capital – available to consider the merits of specific innovation. This is consistent with research from Greece, where a small food business reported not having the resources to invest in digitalisation and being unsure of how doing so could benefit their operations.[61] The limited capability of SMEs to digitalise is a barrier to the supply chain as a whole being able to capture the benefits of digitalisation.[61]

Even among businesses with the capacity to innovate, there will be variation in how feasible it is to incorporate new technologies into business operations and reducing FLW can take time. For example, using robots instead of humans to harvest fruit – which prevents loss by enabling harvesting with less labour resource and potentially by less damage to the fruit – requires that the vines or trees are grown in specific configurations, meaning the technology is not useful to established orchards. See section 3.2 and table 4 for a deeper exploration of barriers to New Zealand producers' adoption of innovation.

Innovation in the form of digitalisation faces specific barriers. Digital product development is shaped by economies of scale, meaning smaller or more diversified businesses are less likely to find digital products meeting their needs.[125] The expected return on investment from digitalisation is different for upstream versus downstream players in the supply chain.[125]

2.3.5 Sharing data is sometimes perceived as a risk to competitive advantage

Data sharing can be seen as risky due to the potential loss of competitive advantage and bargaining power.[126] For digitalisation to prevent FLW, all supply chain participants must be confident both in digitalising their own operations and in sharing their data across the supply chain. Data aggregated horizontally and vertically in the supply chain has value as both a public and private good.[127-129] This can provide disincentives for data aggregators to share data. The potential benefits to businesses downstream in the value chain may also disincentivise actors upstream from sharing their data.[127-129]

Much of this evidence is international. A survey of primary producers conducted by AgriTech New Zealand in 2022 provides some insights for Aotearoa.[130] The majority of producers in Aotearoa are not interested in being early adopters: about 18% say they are "generally one of the first farmers/growers in [their] area to use new digital technology" compared to 82% who say they "prefer to let others try new forms of digital technology before I invest in it". On the wider issue of seeing value in digitalisation, New Zealand producers are more evenly split: 59% see value in existing digital technology while 41% "don't see much value".[130] The split is even closer for getting relevant information about the potential of digital technology: 55% say that it is difficult to work out what may or may not be beneficial for [their] business" compared to 45% who say they "know where to get reliable and impartial information about digital technologies". On data sharing, respondents were evenly split between "being happy to share [their] data with others" and "only shar[ing their] on farm data when [they] are … required to do so".[130] Despite half of respondents saying they only share data when required, smaller proportions said "the risks of sharing outweigh the benefits" (24%) and they "worry about who has access to [their] on farm data" (36%).[130]

> 82% [of New Zealand farmers] say they "prefer to let others try new forms of digital technology before I invest in it".

Based on these results, the barriers to digitalisation on farm identified in the literature are issues in New Zealand, although low trust may be less common. It would be helpful to have similar information on the attitudes of actors elsewhere in the food supply chain towards digitalisation. Understanding attitudes to digitalisation will be necessary to support adoption.

Individual businesses within the supply chain can choose to adopt various digital tools within their organisation, but sharing data across supply chains presents a collective action problem. One way to support digitalisation of the supply chain in the context of potential lack of trust would be for government or a trusted entity to create a suitable platform.

> Understanding attitudes to digitalisation will be necessary to support adoption.

3. Production

Figure 10: A simplified depiction of the food supply chain highlighting the production stage.

Production – where food is grown and harvested – is the first stage of the food supply chain (see figure 10). We use the term 'food loss' when talking about food production in this report, aligning to MfE's definition.[5] However, we acknowledge that not all food lost on farm is accidental; some loss is a deliberate choice, which is often caused by other stakeholders, policies, and regulations in the food supply chain.

Defining when crops or animals become 'food' on farm is highly subjective due to biological, cultural, and economic factors.[131] This section adheres to the broad definition outlined in an earlier report of this series (see *Food waste: A global and local problem*). At this stage of the food supply chain we focus on preventing 'agricultural waste' of food products intended for human consumption. This includes produce that is not harvested due to financial or operational reasons; pre-harvest losses; casualty animals; food rejected on farm because of quality or food safety concerns; and inedible (or not commonly eaten in New Zealand) components of crops and animals not eaten by the intended human market/consumers including husks, cores, offal, lambs tails, and the like. This broad inclusion is reasonable given the ultimate goal is to prevent future food production contributing to further FLW.

> Defining when crops or animals become 'food' on farm is highly subjective due to biological, cultural, and economic factors.

Methods to prevent food loss during production can sometimes be confused with farming methods that increase yield potential. While both prevention of on farm food loss and increases in yield potential can have positive impacts for farmer profitability, they differ in their focus. Food loss prevention in production focuses on both technological and social drivers that prevent crops and animals that are already grown from being lost, whereas yield potential focuses on controlling conditions such as nutrient levels to realise the full genetic potential of the food being grown.[131]

Out of scope for this report are crops grown for seed production and food crops intended for animal feed due to their distinct production and processing chains. For example, maize grown for animal feed is usually harvested and turned into silage;[*] fodder beet may be 'lifted' and stored in sheds or grazed like swedes using the practice of 'break fencing' where the animals eat the vegetables directly from the ground. This is not to say these crops aren't part of the broader FLW landscape, as the land and resources used to produce animal feed crops are arguably better used for food intended for people, but they are omitted here to deliver focused insights on food loss occurring during production of food intended for human consumption.

3.1 Understanding food loss during production

Globally, understanding of on farm food loss is constrained by a lack of data.[132] This is likely due to the technologically difficult and logistically challenging nature of collecting quantitative data about on

[*] Heaped into a pit for anaerobic fermentation to be fed out at a later date.

farm food loss.[133] The few data points that are available rely on farmer estimates – which may significantly underestimate the scale of the issue according to bureaucratic definitions that are challenging to apply in a farm context. For example, one study found Californian farmers' estimates of crop loss were lower than direct loss measurements by 15% (tomatoes) and 21% (peaches).[98]

Despite the lack of comprehensive data, the production stage of the food supply chain has been estimated as accounting for the second largest volume (after consumers) of FLW globally.[134] Currently, there is no national FLW data for Aotearoa (although the baseline measurement work is forthcoming[135]). A recent Australian study, where there is a broadly similar export oriented food production system, estimated that this stage is responsible for around 22% of total supply chain waste,[*] and FLW at production was identified as a previously unrecognised hotspot currently unaddressed by policy.[57]

Compounding the issue of data collection, there is an underlying assumption reported anecdotally by researchers that there is little to no loss happening on farm, particularly in high-income nations like New Zealand, due to access to quality infrastructure and technology, compared with low/middle income nations.[131] This view may be because farmers feel that some waste is inevitable in producing food, and that waste practices (like leaving crops to go unharvested, or leaving food on the ground) are not problems to solve but good stewardship of the land.[136,137] The assumption by farmers that there is little or no food loss on farm may also be because they feel that they are not 'purposely' wasting this food as the drivers are outside of their direct control.

> The assumption by farmers that there is little or no food loss may also be because they feel that they are not 'purposely' wasting this food because the drivers are outside of their direct control.

The discrete, and sometimes interacting, causes of food loss at the production stage presented in figure 11 include direct losses of crops and stock due to economic factors, crops not meeting cosmetic specifications, weather events, operational issues[†] like labour shortages, and animal treatments.[131,133] Many of these factors are already being addressed through incremental improvements in technology that simultaneously improve yields and financial outcomes on farm. For example, upgrading harvesters can address some operational drivers of loss; weather causes can be avoided by selecting species and cultivars that suit the weather patterns of the geographical location of the farm, like growing short-season wheat for summer dry areas; pest management practices, like using nets, can prevent cosmetic damage;[138] and farm hygiene practices can prevent the spread of diseases such as using sprays to prevent mastitis on cow udders.

[*] This estimate, from Australia's National Food Waste Strategy Feasibility Study only accounts for FLW going to disposal destinations (for example, composting and on farm disposal).

[†] Operational drivers refers to events outside of weather that disrupt the usual process of growing and harvesting food. For example, labour shortages are an operational driver because less labour leads to food loss through being unable to efficiently harvest the food before it is overripe, equipment failure like power outages in dairy parlours disrupting the cooling systems, which is then rejected by the processor, and infrastructure damage preventing transport from farms to processors.

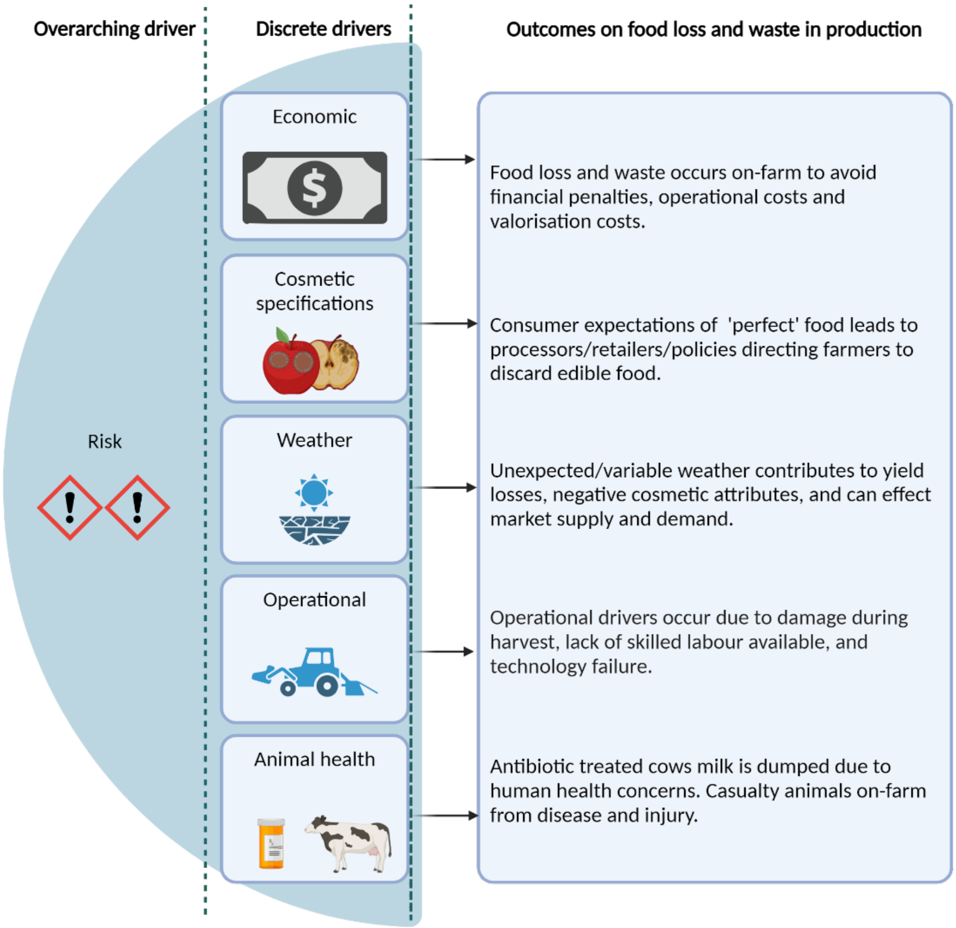

Figure 11: Drivers such as risk, economic, cosmetic specifications, weather, operations, and animal health direct the decisions that generate food loss on farm. Often these drivers are from other stakeholders in the food supply chain. Adapted from O'Connor et al.[131]

Often on farm food loss is caused by other stakeholders in the food supply chain.[136,139] This is largely due to farmers being price-takers[*,137] with relatively little power attempting to avoid risks such as negative outcomes for health, reputation, and finances.[131] As described in section 1.3, *Food rescue in 2022: Where to from here?*, current market conditions encourage farmers and growers to practice overproduction as a buffer against uncertainty in the environment (for example, volatile weather conditions) and markets (for example, consumer demand and price).[136] However, because of the power dynamics in the food supply chain, farmers are often left to dispose of and accept the risks of dumping food on farm. When robust quantitative data is available on quantities of food loss on farm, it would be useful to explore how different business structures within the food supply chain positively or negatively affect loss outcomes on farm. For example,

> …current market conditions encourage farmers and growers to practise overproduction as a buffer against uncertainty in the environment … and markets.

[*] Farmers are 'price-takers' because agricultural produce is largely seen as a commodity (interchangeable undifferentiated products). Therefore, they are exposed to the overall supply and demand conditions downstream in the food supply chain and farmers have little power influencing the price they receive at the farmgate.

farmers and growers that are part of cooperative business models tend to have better negotiating power[140,141] and may avoid some of the onus to dispose of food on farm.

Currently, some of the financial risk of food loss can be abated for some farmers through purchasing insurance when it is accessible or affordable for particular conditions such as hail, fire, and flood,[142] but the tangible disposal of food loss is still the farmers' responsibility. The choice to dump produce is influenced by strong financial incentives due to the high costs of pursuing alternative options and transport requirements from farm to elsewhere.[133] As many of New Zealand's food producers focus on the production of premium produce for high-value export, this also drives waste when some lower grade produce is not sold to protect the value of the premium material and the reputation of the grower/supplier.[47]

As there is no comprehensive national dataset, here we share illustrative examples of food loss occurring during the production stage of the food supply chain for dairy, meat, and horticulture/arable. We discuss what causes food loss, what is currently used that prevents food loss, and future directions for prevention to further improve food loss outcomes during food production in Aotearoa.

The choice to dump produce is influenced by strong financial incentives due to the high costs of pursuing alternative options and transport requirements from farm to elsewhere.

3.1.1 New Zealand dairy sector

New Zealand dairy farmers produce 21 billion litres of cow's milk annually – the equivalent of 4,098 litres per capita in New Zealand – of which 95% is exported to 140 countries.[143] There is an assumption that there is little to no food loss occurring in the production of dairy, but there are very few data points to draw on.[134]

Specific data on sector

Currently, there is no New Zealand industry data that captures food loss on farm – however there is a PhD research thesis in preparation that will provide some data on this.[144] In the meantime, two peer reviewed studies based on dairy farmer estimates have reported between 1%-3% of dairy production is lost on farm in Scotland,[145] and across some European countries.[57,146] These reported losses were largely attributed to milk being disposed of due to antibiotic residues from animal treatments for mastitis. In New Zealand, most waste milks are disposed of either by being fed to calves when seasonally available, or via the on farm manure management system and eventually irrigated onto paddocks.[144]

While the proportion of milk loss is small compared to the milk produced, the volume of loss is still large given the scale of dairy production in Aotearoa. Extrapolating 2% (the midpoint of the two papers referred to above) loss to New Zealand national production (21 billion litres annually), equates to 420 million litres of milk – the equivalent annual production of approximately 98,000 cows[*,4,143] representing unnecessary greenhouse gas emissions, a considerable waste of resources (land, fertiliser, water), and production of surplus calves (see case study 5).

While the proportion of milk loss [on farm] is small … the volume of loss is still large given the scale of dairy production in New Zealand.

[*] Average production /cow/year = 386 kilograms, milk solids ~ 9% of milk. Therefore, an average of 4,289 litres of milk produced /cow/year in New Zealand. Milk loss equivalent = 420,000,000 / 4,289 litres = 97,925 cows. Average methane production per cow per year = 98 kilograms, therefore 97,925 cows * 98 kilograms of methane = 9,596,650 kilograms per year.

Drivers of and issues related to dairy food loss on farm

Overseas markets impose strict requirements for access, setting high-quality standards for milk that processors require farmers to meet, such as low antibiotic residues in milk, and low somatic cell counts.[147] In Aotearoa, the primary treatment for clinical mastitis, an inflammation often caused by bacterial infection in the udder of dairy cows, remains the use of antibiotics due to its effectiveness.[148] In some cases where mastitis isn't caused by bacterial infection, the use of viable alternatives like non-steroidal anti-inflammatory drugs could be further explored.[149,150]

Current factors that prevent dairy food loss on farm

Competition between dairy processors for suppliers, particularly in geographic areas where the smaller independent companies are, and the leading dairy processor being a cooperative, means farmers have more power in dairy supply chains compared to other food industries. Therefore, farmers aren't required to overproduce or deal with surplus milk because dairy processors sell and buy other dairy companies' milk prior to processing in response to fluctuating supply and demand. Further, a memorandum of understanding (MOU) between some dairy processors means less food loss when infrastructure is damaged or interrupted (see case study 3).

> … a memorandum of understanding between some dairy processors means less food loss when infrastructure is damaged or interrupted.

The high value of milk at the global dairy trade means milk at the farm gate is valuable ($7.80 per kilogram of milk solids, which is approximately $7.80 per 11 litres).[151] Therefore, farmers have historically aimed for greater efficiency to improve profitability, which subsequently prevents food loss.[151]

There is also strong political and social pressure for the dairy industry to produce food in a way that enables them to maintain social licence to operate; for example, the implementation of risk management plans.[152] This further incentivises efficiency and non-wasteful mindsets.

Strong relationships between farmers and processors allows liaison and case-by-case assessment as to whether milk would need to be dumped or is acceptable in specific circumstances. This means some food loss on farm can be prevented as some flexibility, facilitated by good communication channels, is built into the system. For example, a cooler breakdown may mean the processor gets the tanker to pick up milk from that farmer last so the milk is cooled by entering a tanker full of already cold milk.[144]

Case study 3: Memorandum of understanding between dairy processors prevents milk dumping on farm

There is an MOU between the South Island independent dairy companies (Oceania Dairy Limited, Synlait, Westland, Open Country, and Mataura Valley Milk) that outlines an agreement that if there is a reason that these dairy companies can't collect milk from their suppliers, or if they have a breakdown at their processing plant, the other dairy processors will take the milk. This is either through purchasing the milk (for a fair price as outlined in the appendices of the agreement) or through a 'swap' where at a later date the amount of milk taken in is returned. This MOU prevents FLW happening due to infrastructure interruption during adverse events. For example, in 2019, flooding on the West Coast of the South Island caused road closures, which meant that Westland Milk could not collect some of its farmers' milk. Supported by the MOU in place, Oceania Dairy Limited sent tankers from South Canterbury to collect this milk from farmers via the Haast highway for several weeks while roads were repaired preventing farmers from having to dump this milk.[153]

3.1.2 Meat production

In New Zealand meat production is largely ruminant (sheep, cattle, and deer) animals, poultry, and pork. Exports account for 80%-95% of ruminant animals,[154] and less than 5% of poultry.[155] The national populations of the species farmed for meat are presented in table 2. Wild meat that is hunted or culled is technically not produced within agricultural systems; however, it is included here as hunted animals are a source of meat that is edible for humans. See case study 4 for some discussion about prevention of wild meat waste.

Specific data on sector

On farm loss of meat refers to casualty animals; that is, animals that die on farm due to natural causes or euthanasia. There is a lack of meat loss data during production because many definitions of FLW do not include animals pre-slaughter/harvest. Consequently, animals that die on farm are often not included during quantification. However, this represents a potentially significant quantity of meat that has been produced but is ultimately lost to the supply chain, and an opportunity for preventing food loss on farm. Clearly farmers have strong incentives to maintain good animal health and diseased animals that go to slaughter can affect the ability of a processing plant to export its products, so losses are kept to a minimum as part of normal business practice.

> …[casualty animals] are often not included during quantification. However, this represents a potentially significant quantity of meat that has been produced but is ultimately lost…

Compounding the issue of data availability are public and consumer perceptions linking animals dying prematurely in our food system to poor animal welfare practices and food safety concerns. This raises concerns that if industries shared the data in the public sphere it could potentially expose these businesses to reputational risks. However, transparent data collection on casualty animals across the industry would provide public reassurance that animal welfare is being well managed. To this end, Beef + Lamb New Zealand have collected this data for sheep and cattle (see table 2).

Anecdotally, the number of animals that die on farm in Aotearoa is expected to be small because sending animals to the abattoir is less affected by time-sensitive decisions such as weather, maturity, and quality attributes than horticultural and arable products.[*] Instead, the decision to send animals to the abattoir is primarily driven by when it is most profitable to do so.[131] While meat farmers are still mostly price-takers, their ability to be flexible with the timing of animal slaughter gives them some power to choose a 'better' deal. Therefore, there is some competition between meat processing companies for farmers' animals. Some farmers will opt to use different processing companies due to space availability, price, whether they are shareholders, and positive experiences with personnel.[144] This, combined with the relatively high value of (particularly ruminant) animals, means that meat producers very rarely dispose of animals on farm. Surplus animals (see case study 5) are usually sent to the abattoir or processor, which on-sells these processed animals as food, or into secondary markets.[156,157] New Zealand's high legislative standards for animal welfare and concerns for the public perception of on farm operations – particularly around the visibility of casualty animals and means of disposal – further incentivises prevention of meat losses on farm.[158,159]

Cattle, sheep, and farmed deer

The number of casualty cattle, sheep, and farmed deer is not recorded consistently. The percentage loss (1.9%-3.6%) provided for cattle, calves, sheep, and lambs in table 2 is based on a Beef + Lamb

[*] With the exception of chickens for meat. Because of breeding selection for greater growth rates/efficiencies and yields, the breeds used in New Zealand (Cobb and Ross) need to be harvested between six and seven weeks of age after this, the chicken's physiology can cause animal health issues.

New Zealand survey of 484 farms in 2017/18.[160] The deer percentage loss is an estimate from a paper published in 2003.[161]

Aotearoa does have a national animal register called NAIT (National Animal Identification and Tracing) for cattle, sheep, and deer.[162] However, the purpose of NAIT is to track movements of animals between farms and processing facilities to prevent and respond to disease outbreaks, so inconsistent reporting of animal casualties occurs, particularly of slinks (lamb and calf fatalities) that aren't recorded in the system.[*] There is also the Dairy Industry Good Animal Database (DIGAD)[163] primarily for tracking breeding worth of dairy animals.

Chicken

In the poultry industry, chickens that die on farm have been anecdotally reported between 1.8 – 2.2%[164] (see table 2). Low mortality may reflect the high standards of animal welfare, and a lack of some poultry diseases in New Zealand.[165] It is unlikely that this estimate accounts for the one-off events that occur, suggesting greater mortality rates on farms that suffer disease outbreaks, barn failures, or operational issues.[166]

Pork

There are approximately 610,000 pigs[167] in Aotearoa; however, access to data of on farm mortality in the pork industry is limited.

Table 2: National data estimates presented for each meat species on population number (based on a 12 month time frame), average liveweight per animal, percentage loss, estimated number of casualty animals, and estimated liveweight of these casualty animals. Abbreviations: kg = kilogram, t = tonnes.

Type	Livestock quantity (millions)	Liveweight per animal (kg)	Casualties (% loss)	Estimated quantity of casualty animals (thousands)	Estimated liveweight of casualty animals (t)
Calves.[†,168,169,160]	5.1	35	2.35	120	4,195
Cattle.[170,171,160]	9.6	467	1.9	182	85,181
Chicken (meat).[172,164,173]	119	2.5	2	2,380	5,950
Farmed deer.[174,161,175]	0.83	85	3.4	28	2,400
Lambs.[*,176,160]	20.9	4.5	2.5	523	2,351
Sheep.[176,177,178,33]	25.5	60	3.6	918	55,080
Total.	181.5	-	-	4,151	161,180

[*] There are also incidences of ear tags falling out of livestock ears adding to missing data issues.
[†] Liveweight is at birth.

Case study 4: Preventing 'wild meat' waste

In the second report of this series – *Food rescue in 2022: Where to from here?*, case study 14 discusses recovery of wild deer meat from culled animals on crown land for food donation as venison mince, but also as a meat product for commercial avenues like Burger Fuel's venison burger. Currently, extraction of wild deer from recreational hunting is estimated at 135,000 animals per year,[179] and 20,000 for commercial use,[180] but is arguably an underutilised resource for meat that can be eaten by people. To recover carcasses from conservation land for meat processing at a MPI approved meat processor, a wild animal recovery operations permit must be obtained by operators.[179] Given the challenging topographies that wild animals are often culled from, usually this meat is recovered through the use of helicopters. Longer travel times by helicopter (15-20 minutes) to reach more remote hunting areas increase costs significantly,[179] making recovery of carcasses from some areas unviable.

Challenge: Costs can outweigh the benefits/value

- Shooting a single red deer from a helicopter in Fiordland costs approximately $90-100, transport and processing adds up to approximately $300-400.[181] Because of this, and fluctuating prices achieved, farmed venison is a cheaper alternative for many customers and food businesses. Other introduced wild meat species such as fallow deer, sika deer, goats, tahr, chamois, and pigs that aren't valued as much or have lighter carcasses may be unviable for retrieval in this way.
- Recovering carcasses takes extra time compared to culling operations, meaning fewer animals are culled on meat recovery trips, which compromises the primary objective of ecosystem protection.
- Associated temperature and timing regulations, and access to a MPI approved meat processor can be prohibitive.
- Browsing pressures caused by high numbers of deer in some areas of conservation land has led to animals that are low weight and are therefore not valuable for carcass retrieval after accounting for costs.[181]
- Charitable suppliers value wild venison meat donations but cannot afford it from recovery operators.[181]

Challenge: Food safety risks

- The use of poisons to manage excessive numbers of introduced predator species are a health risk for meat consumption of animals from these areas, therefore carcasses cannot be retrieved from or near these 'buffer zones'. Buffer zones are generally two kilometres from the area in which poison is applied (depending on species being hunted) and can last up to three years.[182] While mitigated by buffer zones, there is still a risk that any wild meat consumed contains harmful toxins from predator control poisons.
- Contamination of wild meat by bacteria – such as *Salmonella* and *E. coli* – are also a risk and could be detrimental to the consumer.[183]

Opportunities:

- Wild deer that are recovered from private land are usually heavier weights and are closer to processing plants, which reduces transport costs. Farmers also may pay hunters to decrease populations of wild deer near their farmland.[181]
- Charitable suppliers value wild venison meat donations and do receive some from recreational hunters.[179,181]
- There is strong consumer demand in international markets in Asia and the US for meat-based petfood and treats made from New Zealand wild animals such as deer, rabbits, hare, goats, and wallabies. The limit on becoming a significant export market is currently processing capacity, but new plants are being built. This increase in demand and capacity for processing may increase the scale of operations and decrease costs of retrieval as well

as improve prices achieved for the meat.[181] However, this means meat that could be eaten by people is instead used by animals.

- Exploring if risks of negative outcomes can be mitigated while reducing buffer zone areas and duration around poison application would be a useful avenue.
- Financial incentives that enable reduced costs for carcass retrieval might make the process viable.

Unintended consequences

Supporting or encouraging the establishment of business models that rely on 'harvesting' wild meat from introduced species that can be detrimental to native ecosystems may disincentivise efforts towards controlling them to levels where ecological benefits can occur.[184] In some places people will need to be mindful of avoiding reliance on large populations of wild introduced species in their business models where the wider benefit to New Zealand's native and natural ecosystems will take priority.

Case study 5: Surplus/bobby calves, a future food loss issue?

Dairy farmers rely on cows giving birth to a calf every year to begin the milking season. Approximately 22%-28%[156,157] of these calves are kept as replacement heifers; approximately 27%-30% [157] are reared for beef; approximately 5% are euthanised or die on farm;[157] and the remaining 37%-46% (approximately 1.9 million) surplus (bobby) calves are sent to abattoirs annually.[156,157] While the calves processed at the abattoir in New Zealand do not go to 'waste' and contribute to premium export products,[156] public and consumer concerns over animal welfare and ethical implications of this practice are motivating the industry to review surplus calf production, management, euthanisation, and markets.[185]

What has been done generally:

- To address public concerns over bobby calf welfare, animal welfare codes were amended in 2016 outlining transportation and facility requirements of calves younger than 14 days.[186] This has possibly reduced transport fatalities.
- Fonterra announced that changes to their 2023 'terms of supply' means they won't accept milk from farmers euthanising bobby calves on farm – they must be sent to an abattoir.[187] This has likely reduced disposal of meat on farms.

Implications of bobby calves for farmers:

- Typically, farmers are only paid a small amount for each bobby calf (~$30 each). Calves are picked up anywhere between four and 10 days after birth depending on space availability on transport routes and at the abattoir. It is an additional cost for farmers to feed and have shed space for these surplus calves.[144]
- Currently, many bobby calves are bred from sires to decrease the risk of birth injuries and deaths for the cows (for example, Jersey breed sires). These genetics aren't suitable for the beef industry due to the slow growth and small finishing weight of these animals.[188]

Rearing calves for beef is becoming less profitable with rising costs of inputs, intensive labour requirements, animal health risks, and fluctuating purchase and sale prices. A lack of supply chain integration also limits the calf rearing industry. Some dairy farmers report difficulties finding people to take calves to rear as beef animals and are sending them off as bobbies instead.[144]

Solutions being explored:

- Developing a high-value market for New Zealand veal, for example, Pearl Veal.[189]
- Using sexed semen – that increases the incidence of heifer calves born – subsequently decreases the number of cows that farmers need to mate to achieve the desired number of replacement heifer calves, therefore more cows can be mated to beef sires.[190]
- Use of high breeding worth beef breed sires to improve the value of surplus calves for the meat industry.[188] For example, calves bred from Wagyu sires can attract a premium price thereby decreasing the number of bobby calves.[191]
- Alternative uses for some surplus calves, for example, serums for pharmaceutical use are being developed from 12,000 animals grazing at South Pacific Sera farms.[192] Eventually the cattle are processed for beef.

Future solutions

- Extending lactation would reduce the number of surplus calves. Extended lactation of a proportion of animals is commonly used in the dairy goat industry, as high milk volumes can be maintained over two years without the need to produce offspring. Dairy cows are not as suited to this approach in pasture-based systems, but it has been explored in New Zealand. Appropriate cow genetics and feeding are required to maintain good levels of milk production.[193]
- Cell-based production of milk may offer an ultimate solution as no cow means no surplus calf.[194] However, the nutritional value and environmental footprint across the supply chain needs further investigation and the technology is not yet producing quality product at scale.

Drivers of animal casualties

Newborn lambs are at risk of increased mortality because of selection for increased fecundity. Triplet lambs have lower birth weights and are more vulnerable to seasonally wet and cold conditions in spring.[195] Likewise, during calving, cold and wet conditions have been observed to affect casualty animal incidences.

Disease outbreaks, and injuries incurred on farm that are not treatable or are unresponsive to treatment can lead to euthanisation; for example, *Celostridium*,[196] *Camplybactor* and *Salmonella* infections, fractured bones,[197] broken limbs, or 'black mastitis'.[144] Operational issues or breakdowns can also cause animal death; for example a breakdown of a barn ventilation system can result in mass chicken casualties.[166]

Current factors that prevent meat food loss on farm

Improved and audited standards of animal care have probably incrementally decreased casualty animals. There is ongoing industry support to improve stockmanship and animal health outcomes such as PigCare™,[198] and New Zealand Farm Assurance Programmes.[199] Further, there has been cross-sector collaboration initiatives to improve parasite and disease management, which subsequently reduces animal casualties. These initiatives include Wormwise,[200] Ovis Management,[201] and the Eliminating Facial Eczema Impacts programme.[202]

There is ongoing development and uptake of appropriate genetics for reduced susceptibility to disease, and animal health technology. Improvements have been made through adoption of vaccines,[196] improving parasite management practices, and uptake of cow monitoring collars on dairy farms. These technologies decrease the occurrence of diseases as well as enable early detection of health issues preventing on farm casualties.[144]

Anecdotally, some animals are butchered on farm and some farmers will use the meat of euthanised animals for their own food[144] as well as a source of dog meat, or for trading through informal networks. Some farmers will also occasionally consume lambs' tails as a 'farm delicacy' (see case study 6).

Finally, improvements in the transport of animals between farm, saleyard, and processor have been implemented through the New Zealand Livestock Transport Assurance programme and may have reduced the incidence of casualty animals during transport and condemnation of animals on arrival at slaughter plants.[204]

> **Case study 6: Lambs' tails: a food opportunity?**
>
> Another source of meat that is lost on farms are lambs' tails, which are routinely removed during tailing (docking) to prevent flystrike – a serious animal health concern. In Aotearoa there are approximately 20.9 million lamb tails 'harvested' annually.[177]
>
> Currently lamb tails are not collected for sale as a food in New Zealand; however, some farmers enjoy eating them as a delicacy, cooking lambs' tails on a grill over a fire to burn off wool, and sometimes finished in a steamer. In South Africa, lambs tails (Skaapstertjies) are sold at supermarkets as a barbeque (Braai) snack.[203] Could there be an opportunity for utilising this part of the animal as added income for sheep farmers through selling lambs' tails as food into appropriate markets?

3.1.3 Horticulture and arable

Fruit and vegetable growers in Aotearoa produce over 2.5 million tonnes of fruits and vegetables annually across over 50 different species including kiwifruit, grapes, apples, cherries, avocados, onion, and tomatoes[205] (see case study 1). Some crop species including kiwifruit and apples are valuable as export products – kiwifruit annual exports are valued at about $2.5 billion and apples at $902 million. Most produce enters domestic retail channels via wholesalers, trading floors, or direct delivery to retailer distribution centres before being on-sold to consumers. New Zealand's arable industry produces 800,000 tonnes of grain annually[*] including wheat and barley, which are milled into flours for use in both domestic and export products, as well as vegetable oil crops such as canola.[206]

Packhouses are an integral intermediary between producers, wholesalers, retailers, and exporters.[205] These facilities ensure that fruit and vegetables meet food safety standards as well as quality specifications.[207] Generally, horticultural goods that arrive at a packhouse are washed, graded, and packed – in crates, boxes, or their final packaging – before being placed in cool storage.[207] Some packhouses manually grade produce, while others may use advanced optic and robotic technologies to streamline the process.[208,209] Graded out produce that is deemed unmarketable is then used either for further processing into secondary markets, donated to food banks, or disposed of through going to animal feed, composting, or landfill.[51,210,211]

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Specific data on sector

Outside of Aotearoa, horticultural food loss (fruit and vegetables) has been estimated as having the largest volume of waste on farm, estimated to be 23%-26% of total production.[57,134] While there are

[*] For this report we exclude seed production (for example, radish seed or carrot seed) and animal feed production.

many instances reported anecdotally of food loss happening on farm pre- and post-harvest, table 3 shows some of the few New Zealand specific examples that are available. See annex 1 for an overview of technological solutions and management practices for food loss prevention in horticulture and arable crops.

Table 3: New Zealand specific data on horticultural crop pre- and post-harvest losses. Rounded to the nearest whole percentage.

Crop	Pre-harvest % losses	Post-harvest % losses	Context
Glasshouse tomatoes.	14	3	From direct measurement of unharvested tomatoes and rejected tomatoes at a glasshouse.[212]
Apples.	10	16	Estimates from a report that surveyed 15 growers (accounting for 65% of orchard land) from Central Otago in 2021. Pre-harvest losses are farmer estimates of unharvested fruit. Post-harvest losses include harvest and process losses.[213]
Apricots.	6	12	
Cherries.	8	14	
Nectarines and peaches.	4	12	

Causes

The few studies focusing on food losses on farm in Aotearoa have identified several causes including weather events – for example, rain events causing splits in fruit;[213] lack of labour; and the influence of product specifications on harvesting choices.[213]

A grower's produce will vary in appearance and quality attributes due to genetic variation within some cultivars, pests, diseases, and weather or soil factors (see figure 12). The value of this varying produce is determined by product specifications applied by retailers, wholesalers, and packhouses. These specifications outline taste and texture attributes, specific sugar content/brix percentage, and cosmetic specifications such as appearance, size, and weight. Product specifications are necessary in some instances as they ensure that produce is transportable, meets Overseas Market Access Requirements, is safe to eat, and of a reasonable taste and texture.[*]

> The value of…produce is determined by product specifications applied by retailers, wholesalers, and packhouses.

Similar to Australia's agribusiness environment,[137] New Zealand's horticulture sector consists of a concentrated and oversupplied market with few retailers and subsequently low market power of growers. Therefore, growers must accept limiting practices by other stakeholders and their stringent conditions to sell their produce, including specifications and a lack of access to the exact crate determined by the retailer (see case study 7). When these conditions aren't met, growers do not receive payment, and have the additional burden of discarding 'unsellable' product. Sometimes transferring unaccepted produce to other buyers or secondary markets (preventing food loss) is not an option for growers due to exclusivity clauses in some supplier contracts; although this practice is in theory no longer permitted under the Grocery Supply Code (see box 8). Anecdotally, wholesalers and retailers vary specifications with little notice depending on market fluctuations in supply and demand.[214] This can significantly affect the price growers receive for their produce and the quantities of crops that are wasted. Where prices achieved for the crop equal the cost to harvest, the farmer

[*] Arable crops are not as sensitive to FLW causes due to cosmetic specifications as these crops usually require further processing before being sold to consumers.

will opt to either partially harvest or leave the crop in the field, and when available and cost efficient (or allowed) use the surplus as animal feed or contact gleaning services (see figure 12).[213]

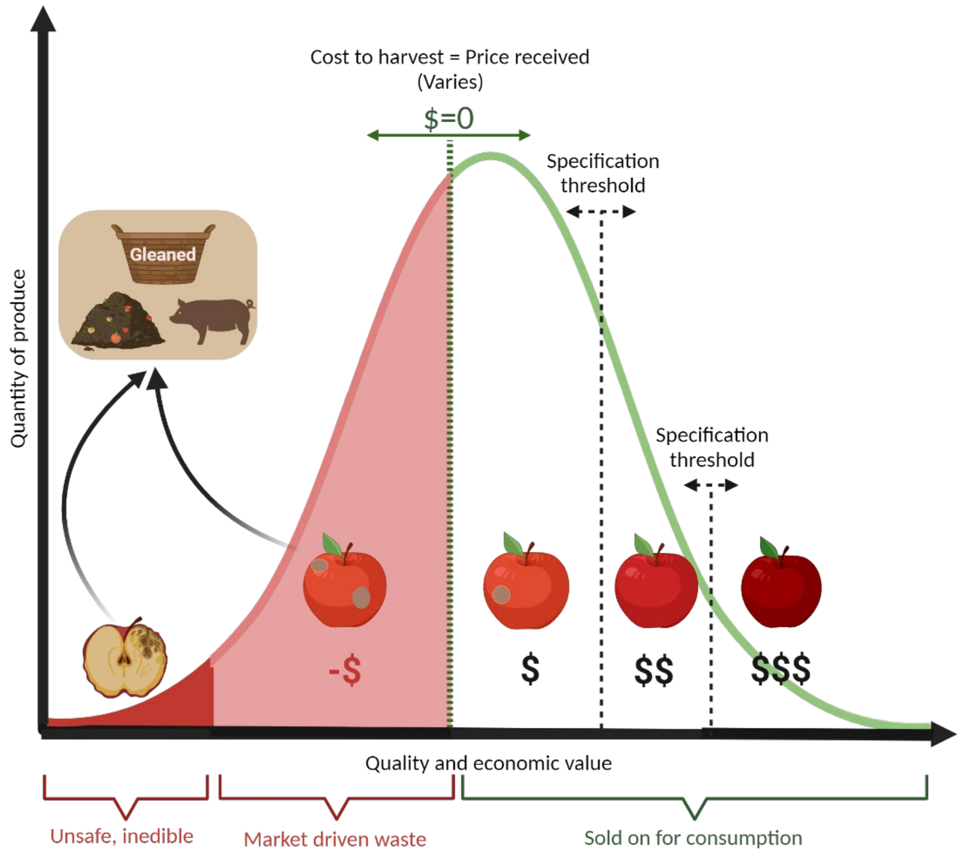

Figure 12: Fruit and vegetable crops exist on a spectrum of quality attributes due to genetic, biotic (pests/disease), and abiotic (soil/hail/sunshine) influences. The economic value of the produce is reflected by the standard of specification that the food achieves (as set by wholesalers and retailers); this can vary depending on supply and demand (market driven). When the cost to harvest is equal to or greater than the price received ($ = 0), this drives decisions that cause on farm food loss.

Further, the portion of a grower's crop that meets specifications varies significantly between 'good' and 'poor' growing seasons causing significant quantities of waste on farms. In Central Otago, 'good' and 'poor' season yields for cherries have been identified as varying as much as 50%.[213] The main cause of 'poor' seasons were rain events that cause the cherries to swell and have split skins, therefore no longer meeting fresh produce specifications and being left unharvested.[213] Currently when specifications are not met many types of fresh produce have few viable secondary markets like processing into other food products such as frozen, juice, or puree.

Growers face variable climates, low market power, stringent specifications, and variable prices. Given these uncertainties, growers are driven to produce surplus food (causing more food loss) as a financial risk mitigation strategy.[137] This locks our food system into the cycle of using valuable natural resources, emitting greenhouse gases, and wasting nutritious food.

> Given [the uncertainties growers face] … growers are driven to produce surplus food (causing more food loss) as a financial risk mitigation strategy.

Case study 7: Returnable plastic crates and their impact on FLW

Returnable plastic crates are used in New Zealand for packing produce for transport from farms to wholesalers and retailers. These crates are an alternative to disposable crates and are an effective way to transport produce without generating plastic or cardboard waste.[205] However, they can also generate food loss.

New Zealand's main supermarket retailers, Woolworths NZ (formerly known as Countdown) and Foodstuffs North and South Island, require suppliers to use produce crates from three specific companies, based on exclusive supply agreements with the crate companies. The crate companies are: Viscount FCC; Loscam; and CHEP. Foodstuffs NZ will only accept the green crates (see figure 13) and Woolworths NZ will only accept the black crates (see figure 13) whether the producer is supplying the store directly or via a wholesaler. Crate dimensions differ by only a few millimetres yet they are not allowed to be used interchangeably, and no alternatives (for example, cardboard boxes) are permitted.

In the busiest weeks for retail, there is always a shortage of crates from at least one of the crate companies. This problem is worse in the summer at the peak season for harvest for many crops. The 2023-24 Christmas and January period was the worst to date, with Viscount FCC closing their distribution centre for two weeks, creating a backup of crates to process (clean and redistribute to growers). In the meantime, Foodstuffs NZ's suppliers couldn't turn to the black crates as a substitute.

Growers anticipate the problem and stockpile crates before the busy season, ordering more than they need, knowing they'll only get a fraction of what they order from the crate companies. Meanwhile, retailers are not incentivised to return crates from stores to the crate companies for cleaning and redistribution. Ultimately, if a grower can't get the right crate at the right time, there's no alternative way to market. Therefore fresh produce that meets retailer specifications is left with the grower for disposal.[214]

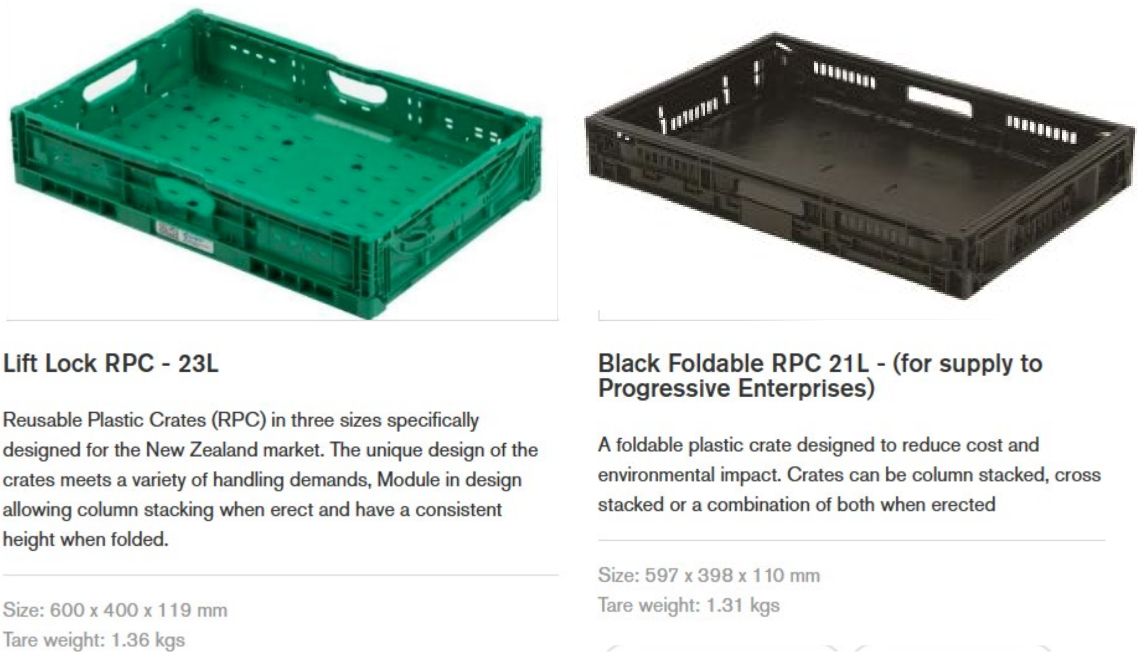

Figure 13: Growers supplying Foodstuffs NZ must use the green crates (left),[215] growers supplying Woolworths NZ must use the black crates (right).[216] Image credit: CHEP; permission pending.

Drivers of and issues related to horticulture food loss on farm

Variable factors such as weather events cause produce losses and damage,[213] and global and domestic market factors result in variable prices achieved for produce.[19] There is also a lack of access or existence of secondary markets for produce that is not accepted by the packhouse or the processor due to cosmetic damage.[51]

Constrained access to labour availability/skill and operational factors affect pre- and post-harvest food loss occurrence, leading to damage during harvest due to rough depositing of fruit into bins. However, this has been somewhat abated with an increase in the cap on Pacific workers from 2023.[51,217]

The low level of market power – particularly for producers of domestic goods – when selling produce to wholesalers or retailers leads to overproduction to mitigate financial risks.[137,214] This is compounded by a lack of transparency or forecasting of prices affecting choices around timing of harvests or whether to harvest a crop at all.[214] Further, terms of supply with retailers and wholesalers sometimes prevent growers opting for secondary markets with their surplus produce.[51]

Current factors that prevent horticulture food loss on farm

Food loss is reduced by adoption of practices such as using greenhouses, installing nets, two dimensional (2D) orchards, or 'strip picking' where all the fruit is picked and automated systems at packhouses sort the fruit into their categories. Strip picking prevents on farm food loss as the fruit is now accessible for distribution to secondary markets.[213]

Uptake of a wide array of technology types can improve yields and subsequently prevent losses. Technologies include mechanisation of harvesting methods like picking platforms,[51] using specific cultivars that are bred for disease tolerance, and using genetically uniform cultivars.

Some growers use gleaning services and subscription boxes (for example, Wonky Box).[29] However, there are concerns around gleaners due to possible health and safety risks of having volunteers on farm and subsequent liability for the grower.[214]

3.1.4 Fishing and aquaculture

We have previously produced an evidence synthesis on commercial fishing *The future of commercial fishing in Aotearoa New Zealand*. A source of preventable loss in commercial fishing is non-target fish being captured in nets. In that report's case study 6.3.4, we describe technology that can prevent this, including specialised nets. Additionally, our previous report in this series, *Beyond the bin: Capturing value from food waste*, discusses material recovery, which comes into play when prevention is impossible.

3.1.5 What are the gaps in our knowledge?

Across food types, quantities of food lost on farm are unknown because it isn't routinely measured or even identified as being waste. Farmer estimates may underestimate proportions unharvested. Direct quantification is technically difficult and time consuming, but increasingly possible through use of technology. The benefits of such data collection are not just a better understanding of the issue and its scale, but also the identification of opportunities to attract innovative solutions and entrepreneurship in addressing the issue. This issue is covered in detail in *The future of commercial fishing in Aotearoa New Zealand*.

As well as specific quantitative data, there are gaps in our understanding of the effect of the operations of markets on food loss on farm through factors like:

- Business structures (for example, cooperatives versus corporations).
- Relative market power.
- Competition and competitive behaviours among retailers and processers.

- Mechanisms for sharing risk and responsibility for FLW across the supply chain.
- The role of consumer preferences in setting specifications and the adaptability of these preferences.

Better understanding of these aspects of market operations may suggest policy levers for preventing food loss on farm.

3.2 How can we prevent food loss during production?

It is important to view any recommendations that may impact farmers through the lens of farmers' financial and market power capacity. Current economic climates for many farmers in New Zealand are difficult due to disruptions and labour shortages during COVID-19, and large weather events such as Cyclone Gabrielle. Further, the cost to produce food has increased, putting pressure on farmers' business margins because of increases in input costs like fertiliser and labour, and high mortgage interest rates. Imposing any additional burden on farmers to address FLW issues during production needs to be seen in the context of farmers' relatively weak position to make changes in the overall food system or add value to offset costs or investment into FLW prevention technologies and strategies.[130] Therefore, the following potential solutions for food loss on farm will often require support from other stakeholders to implement.

3.2.1 Potential solutions

Data collection and sharing: addresses all drivers

Adoption of agreements like an MOU – rather than a non-disclosure agreement – for growers and farmers to share FLW estimates with researchers would significantly benefit efforts to address on farm food loss through enabling this data to support quantitative and causative research and subsequent solution implementation. This could be undertaken through expanding the capacity of currently available platforms such as Trust Alliance New Zealand (see box 3), Integrape, DIGAD, and NAIT. Further, where data is currently not collected, real time data collection and sharing would strengthen the operation of secondary markets.

Box 3: Trust Alliance New Zealand

Trust Alliance New Zealand is a non-profit food and fibre industry consortium of farmers and growers, governed and operated by members,[218] which aims to use decentralised distributed ledger technologies (DLT) to enable farmers to be in control of their own data and store, protect and share it effectively.[219] Trust Alliance New Zealand is co-funded by members, and Sustainable Food and Fibre (SFF) Futures from MPI and aims to improve collective profitability.[218] The consortium is currently exploring the concept of a 'Digital Farm Wallet' to "unlock value from farm data" and be able to easily share and verify information between farmers, industry, and retail while ensuring trust and privacy. Transactions sent across the network need to be verified by other members (farmer owned organisations) allowing farmers and growers to retain control and ownership of their data.[93] Conceivably, expanding the capacity of a tool like a Digital Farm Wallet to incorporate FLW data supplied by farmers could be a valuable and accessible opportunity for identifying food loss occurrence and opportunities during production.

Secondary markets: addresses economic and cosmetic specifications

Supporting access and increased capacity of networks that enable secondary markets for foods that are not cost-effective to harvest for their primary market would enable this food to be better accessed by other potential customers, such as processors. This would also benefit efforts at other levels of the hierarchy, like upcyclers, subscription box services, and food banks.

Supporting the development of viable and flourishing secondary markets for all food types, such as rendering facilities for meat by-products, and juicing/spray-drying/pureeing facilities for edible produce that doesn't meet specifications would reduce FLW from the system as a whole.

Technology: addresses operational, animal health, and economic drivers

Supporting development and adoption of accurate real time data collection technologies (such as light detection and ranging (LiDAR), see table 4) for use on farm pre-harvest would enable accurate data collection on the scale of FLW occurrence, but also enable forecasting and food loss prevention decision making through agronomic analysis of crops as they grow.

Encouraging innovation and research could address key drivers of FLW on farm across food types and enable prevention and informed decision making around food loss. To be effective, innovation from research needs to be scalable for export markets so, for example, robotic technology can be produced and sold at scale, decreasing price barriers for adoption by New Zealand growers. Examples of technologies that could address food loss drivers are listed in table 4.

Policy actions and terms of trade: addresses economic, operational, and cosmetic specification drivers

Encouraging whole crop purchasing to enable full harvests, therefore facilitating 'out-of-spec' food to be used in secondary markets (because it is already at the packhouse/processor) could make a large impact on reducing FLW.

Removing exclusivity clauses for crops that have a high incidence of food loss occurrence due to financial drivers would allow this food to have a chance to be sold to another market/customer. This is addressed in the Grocery Supply Code and influences the market power of farmers. It may have an affect (positive and negative) on price achieved for some grades of produce.

Some niche solutions

Vertical farming of some crops – grown entirely indoors under artificial light in urban areas – is emerging internationally and locally (see case study 8). Vertical crop growing decreases weather and cosmetic specification causes of food loss during production.[220]

Another niche solution gaining momentum in food production is cellular agriculture. Creating food using this method enables more precise control, avoids overproduction, and is currently in development for some foods such as dairy, meat, eggs, some plant products, and raw ingredients.[194]

Case study 8: Innovative vertical farming techniques at Greengrower

Greengrower is a company that produces lettuce, microgreens and other salad leaves located in Hamilton. All of Greengrower's produce is grown indoors (see figure 14), and each 5,000 square metre farm produces as much as 150 hectares of conventional growing. Seeds are planted in specialised plugs containing growing medium. Newly planted seeds are kept in a 'nursery' for seven to 11 days and then either harvested for microgreens or transferred to the main growing area. The main growing stage requires a further two weeks, and the maximum production time from planting to harvest is four weeks, compared to six weeks for conventional growing.

Figure 14: One stage of lettuce production at the Greengrower indoor farm.

The innovative approach to growing reduces food loss in their own operations, and food waste for their retail and household customers. Because the produce is grown indoors, it is not vulnerable to pests or weather, providing more certainty around yield. The indoor growing conditions as well as the absence of pests also mean the leaves don't need to be washed before packing, preventing loss through damage and lengthening shelf life, potentially reducing retail and consumer waste. One of Greengrower's food service customers reports that certain conventionally grown salad leaves are wasted due to large unpalatable cores; Greengrower's leaves are larger and don't have cores, resulting in greater utilisation by the customer.

Table 4: Technology currently available and the FLW drivers it addresses on farm. Each technology is presented with a simple SWOT analysis through the lens of food loss and waste prevention. Abbreviations: AI = artificial intelligence, CRISPR = clustered regularly interspaced short palindromic repeats, FLW = food loss and waste, GMO = genetically modified organism (here it is synonymous with GE = genetically engineered), IP = intellectual property, LED = light emitting diode, LiDAR = light detection and ranging, RGB = red green blue (camera), SWOT = strengths, weaknesses, opportunities, threats, UV = ultraviolet light.

Technology and FLW driver addressed	How it works	SWOT: Strengths (S), Weaknesses (W), Opportunities (O), Threats (T)	What needs to happen to improve FLW on farm:
Wearable health monitors. <u>Driver</u>: Animal health.	Wearable monitors that track rumination (feed intake), temperature, movement, etc. and use this data to alert farmers if an animal is sick, on-heat, eating enough, etc.	**S** Simple to implement, accurate data collection, the two main companies in NZ (Sensehub/Allflex and Halter) have effective user interfaces that help farmers make day-to-day decisions that benefit health of animals and lower the chance of casualty animals.[221] **W** The cost of subscriptions may make it unviable for some. Currently collars need to be in range with readers, which is difficult in some rural topographies. Animals having collars and trackers on them could become an animal welfare issue due to added weight, chafing on skin, and use for virtual fencing. **O** Further adoption and data collection. Could potentially use this data for industry wide perspectives, adopt for other animal types. **T** Adoption by farmers needs to balance costs versus value. Higher resolution detection of subclinical issues may lead to greater antibiotic use and more milk waste on farm.	The technology would need to become business as usual and scaled to suit more farmers.
Development of plant varieties through classical breeding, genomic selection, and genetic marker methods. <u>Drivers</u>: Cosmetic specifications; weather; and operational.	Breeders develop varieties with specific attributes to increase pest/disease tolerance, shelf life, and adaption to climates.	**S** NZ unique varieties that are tailored to fit our way of producing food and consumers in export markets. Genetically uniform cultivar types (for example, asexually propagated potato varieties) help create uniform produce and therefore more quantity should meet specifications.[222] **W** Long timelines for developing varieties (10+ years for some species) is expensive, requires several sites around the country to capture the genotype by environment interaction effects on phenotypes. Sometimes training populations can take years to phenotype due to species specific requirements, therefore breeding objectives are focused on novel traits (e.g. red kiwifruit), or improving yield potential rather than improving FLW outcomes on farm. **O** Development of unique and valuable IP that can be a valuable export. Building a pool of unique, diverse (but well characterised)	The development of cultivar development efficiencies that shorten timelines (and cost) for getting improved cultivars to growers. Breeding objectives that focus on reducing FLW (for example, traits that prevent fruit fall during wind weather events).

Technology and FLW driver addressed	How it works	SWOT: Strengths (S), Weaknesses (W), Opportunities (O), Threats (T)	What needs to happen to improve FLW on farm:
		germplasm provides important resources for adapting economically important species when future issues arise.[222] **T** Because of biosecurity risks and concerns, it is difficult to import germplasm for some economically important species because of strict regulations and expenses associated with following protocols. However, some steps are being made by the Plant Germplasm Import Council to address this.[223]	
Use of GE methods to develop novel cultivars. <u>Drivers:</u> Cosmetic specifications; and weather.	Using modern breeding technologies to fast track and improve the genetics of plants to express desirable phenotypes.[224]	**S** GE can be faster than classical breeding. Novel trait development can be attained when needed for resistance or tolerance of new diseases or pests. **W** Currently GE is expensive to implement and requires very specialised expertise and facilities, but development of new methods (like CRISPR) and protocols are decreasing costs.[225] **O** GE is a tool that can address multiple issues (such as yield, nutrient use, or emissions).[225] This technology provides the opportunity to develop unique and valuable IP and products, and enables future proofing against changing climate stresses. **T** Currently, GE faces regulatory barriers, driven by concerns of its potentially negative impact on NZ food exports to overseas markets. It is also a politically controversial topic, with concerns about the risks of unintended consequences, for example, what is the impact of upregulating specific expressions in food plants and their impacts on nutrition and health for consumers?	Adoption and scaling the use of GE in New Zealand would require assurance from overseas markets that using GE in NZ will not have a detrimental impact on NZ exports. A change in policies that support research in NZ and enable development for NZ growers is also needed before this technology can be applied to FLW issues.
UV or LED treatment of plants. <u>Driver:</u> Cosmetic specifications.	Using different spectrums of light at different stages of a crop induces plants to upregulate their natural disease resistance functions.	**S** UV or LED treatment can decrease the requirements for growers to use agrichemicals to prevent blemishes on produce from diseases etc. Using these treatments may enable farmers to better match supply with market demand through controlling rates of crop growth. Subsequently, this would reduce market driven waste. These treatments are available in NZ through businesses such as BioLumic.[226] **W** Currently these treatments are effectively applied for indoor growing only, therefore inaccessible for most crops.	UV or LED treatment technology would need further development to fit more crop types.

Technology and FLW driver addressed	How it works	SWOT: Strengths (S), Weaknesses (W), Opportunities (O), Threats (T)	What needs to happen to improve FLW on farm:
		O Combined with robotics, exploring if these technologies can be effectively used in the field may increase uptake by growers. **T** Other options, like agrichemicals and breeding for tolerance, are currently effectively used and accessible for pest/disease management, therefore uptake of UV or LED treatments may be slow.	
Optical technologies that facilitate growing and harvesting for example, LiDAR and RGB cameras. <u>Driver:</u> Operational.	Using optical technologies as a real time data collection method to identify when crops are ready for harvest, forecast potential issues, early identification of pest and/or disease.	**S** Optical technology enables accurate and fast collection of data with fewer labour requirements than manual quantification methods. **W** Optical technology cameras can be expensive. Further, this technology generates a lot of data that requires analysis and interpretation. Creating models that make sense of this data for specific crops/cultivars is complex. **O** AI models may make optical data easier to manage, analyse, and interpret. Costs of optical technologies are decreasing.[227] **T** Crop specific optical technologies are expensive to develop for a small market such as NZ, therefore development and manufacturing costs makes these technologies expensive to attain and maintain, erode profitability, and are a significant barrier for startups in this space, and growers who would benefit from these technologies.	A possible solution is through incentives that encourage the development of technologies locally that can also solve issues in bigger markets and can be exported, while enabling local growers access to adopt this technology.
Mechanisation of harvesting. <u>Drivers:</u> Operational; cosmetic specifications; economic; and labour	Mechanisation (different to robotics) that enables efficient use of labour for example, dairy parlours, picking platforms, and e-bins.[228]	**S** Mechanisation improves efficiencies of harvesting and milking procedures, reduces the time taken, and can reduce the incidences of fruit damage therefore causing less food loss. Mechanisation on farm is already extensively used in dairy parlours, and some options are developing for orchards.[51] **W** Initial upfront cost to purchase and implement mechanisation technology can be prohibitive for farmers.[130] Only some technology is available and sometimes this is crop or production process specific, which would require major shifts in farm operations to incorporate.	Addressing health and safety concerns and possible liabilities of using mechanisation on farm would improve confidence in utilising picking platforms for harvesting. For seasonal needs, businesses that offer leases for this equipment (such as e-bins) may improve the economic viability for growers and improve adoption.

Technology and FLW driver addressed	How it works	SWOT: Strengths (S), Weaknesses (W), Opportunities (O), Threats (T)	What needs to happen to improve FLW on farm:
		O Over time, using mechanisation can decrease the cost of labour to harvest, therefore more of the crop is economically viable to harvest and less market driven FLW occurs. **T** There are some barriers to adoption of mechanised operations, such as picking platforms, due to health and safety concerns for staff and subsequent liability risks for farmers.[51]	
Robotic technologies. <u>Drivers:</u> Operational; cosmetic specifications; and economic.	Robotics that apply specific inputs and harvests fruit when it is ripe without damage.	**S** Using robotics could decrease the amount of fruit that goes unharvested due to labour shortages. NZ has expertise developing these robotics (for example, at AgriTech, Callaghan Innovation, Plant & Food Research, AgResearch etc.). **W** Developing robotic technology requires large upfront investment, which can limit access and uptake by growers. Adopting robotics into farm systems would likely require significant changes to the operations on farms, like changing tree spacings to suit machine requirements. **O** Instead of individual farmers buying robots, contracting businesses could service geographic areas (like silage operators). Development of robotic technology products can also be valuable for export markets. **T** Development of robotics for specific plant species or cultivars for NZ growers' specific needs is limited as the domestic market is too small to support scale up of robotic businesses locally.	Development of robotic technologies by NZ businesses that can also solve issues in bigger markets (i.e. can be exported) so that start-up robotic companies can scale, possibly making the technology affordable and accessible for local growers.

Technology and FLW driver addressed	How it works	SWOT: Strengths (S), Weaknesses (W), Opportunities (O), Threats (T)	What needs to happen to improve FLW on farm:
Farm data digitisation. <u>Drivers:</u> Operational.	Data centres that enable collection and sharing of data by farmers. These services aid decision making and enable the identification of waste quantities and occurrence.	**S** Farmers are already collecting some types of data for various regulatory, business, and biosecurity reasons. **W** Farmers don't currently collect data on what FLW is happening on farm. Many would need support about what to measure, how to measure, and how to input food loss data appropriately. **O** Collating these data types can help with forecasting and decision making for the farmer that may enable prevention of FLW. Some decentralised data platforms already exist in NZ such as Integrape and Trust Alliance NZ (see box 3). **T** There could be some concern around data sharing and data use. However, this has been somewhat addressed by Trust Alliance NZ where farmers have control over what data is shared and who with. Currently there are no persuasive incentives or value for farmers to collect data on food loss occurrence on farm to be shared. Negative reputational risks may be a concern in sharing food loss data.	Better articulating the value for farmers to collect and share their food loss data through data centres would incentivise adoption. Further training and ongoing assistance would be needed to support farmer uptake of data digitisation and sharing. These data centres could prevent food loss through informing better decision making on farm, and highlighting opportunities for FLW reduction.

4. Processing and manufacturing

Figure 15: A simplified depiction of the food supply chain highlighting the processing and manufacturing stage.

In the food supply chain, processing and manufacturing refers to the transformation of raw agricultural produce into a new ingredient, good or product (see figure 15). Food processing is any deliberate change to raw food, such as through cutting or drying, or mixing and combining ingredients.[229] Manufacturing describes the whole process of making a new good or product, including packing, labelling, and storing as well as the equipment and labour involved. The methods used in processing and manufacturing depend on the specific good or product being produced and can depend on several actors. This section will focus on the actors carrying out sorting, processing, and packaging of food that has come off the farm, and larger-scale or commercial settings where processing or manufacturing of food typically occurs in bulk, according to predetermined formulae or recipes to be sold at a later date (i.e. not food service or restaurants – which are discussed in section 5).

Food processing and manufacturing not only provide economic value through the creation of new goods or products but also have wide reaching environmental and social effects. Processing increases palatability, reduces the incidence of pathogens that could contribute to illnesses and usually extends the shelf life of food to prevent spoilage, making it a key stage in preventing FLW.[229] However, food processors may create large volumes of FLW due to the scale of their operations and specialised production, where only part of an ingredient might be used in their production resulting in large quantities of by-product(s).[230] For manufacturers and processors, the benefits of preventing FLW are not only the positive environmental impacts, but also the potential for greater profitability and improved public perception of a company.[230] There are opportunities to prevent FLW both through and within processing and manufacturing.

Processing...usually extends the shelf life of food to prevent spoilage, making it a key stage in preventing FLW.

There are opportunities to prevent FLW both through and within processing and manufacturing.

Advances in food processing and manufacturing over the last century have increased the availability of a variety of food ingredients and products through technologies such as cold chain logistics, additives and preservatives, and packaging. This has resulted in the development of a wide range of food products, an extension to the shelf life of food, and, for some people, increased the range of foods available to eat. The manufacturing and consumption of a final product can now take place at a great distance away from where the raw ingredients were grown, and involve many actors including suppliers, processors, and distributors.[231]

Food processors and manufacturers can affect FLW not only in their own operations, but across the supply chain. For example, the way food is packaged and labelled can affect retailers' or consumers' behaviour and thus the likelihood of waste generation further down the supply chain. For example, fresh tomatoes typically go through a decontamination process and are packaged in plastic – a trade-off between protecting and extending the life of the product to prevent FLW and the creation of plastic waste (see *Rethinking plastics in Aotearoa New Zealand*) – and labelled with a best before or expiry date, which indicates to retailers and consumers when to stop selling or dispose of the product.

Digitalisation and the integration of new technologies can also help support the quantification of FLW and any prevention interventions at this stage. However, there is a need for sufficiently detailed data to understand the extent of FLW in processing and manufacturing as well as to be able to evaluate the effectiveness of interventions, including their impacts elsewhere in the supply chain.

Levels of food processing

As processed foods have become a more significant part of modern diets, food processing classification systems have been developed and are typically used in epidemiological or dietary research. The degree of processing ranges from sorting fruit or slaughtering animals to the production of ultra-processed foods (UPF). UPF can undergo transformation through multiple technological processes, typically to isolate chemical components such as sugars, proteins, or fats, and can have several highly manipulated ingredients.[232] There are several different classification systems used globally, typically using three to five groups to indicate the degree of processing.[233] One common example is the NOVA system, which has four groupings (see figure 16). Group 1 captures minimally processed or unprocessed foods that have been sorted, dried, frozen or packed; group 2 includes food that has been processed for ingredients including refining NOVA group 1 foods to be used in seasoning or cooking such as pressing olives for oil, or milling and refining wheat for flour; foods in group 3 are created by adding salt, sugar or combining NOVA group 2 ingredients to make items such as bread, cheese, canned fruits and vegetables; foods in group 4 are ultra-processed and contain additives made using highly modified ingredients using specialised, industrial techniques such as hydrogenation, for cosmetic or sensory properties. Group 4 is a broad category ranging from biscuits, confectionary and ice cream to instant noodles, hot dogs, and sauces.[232]

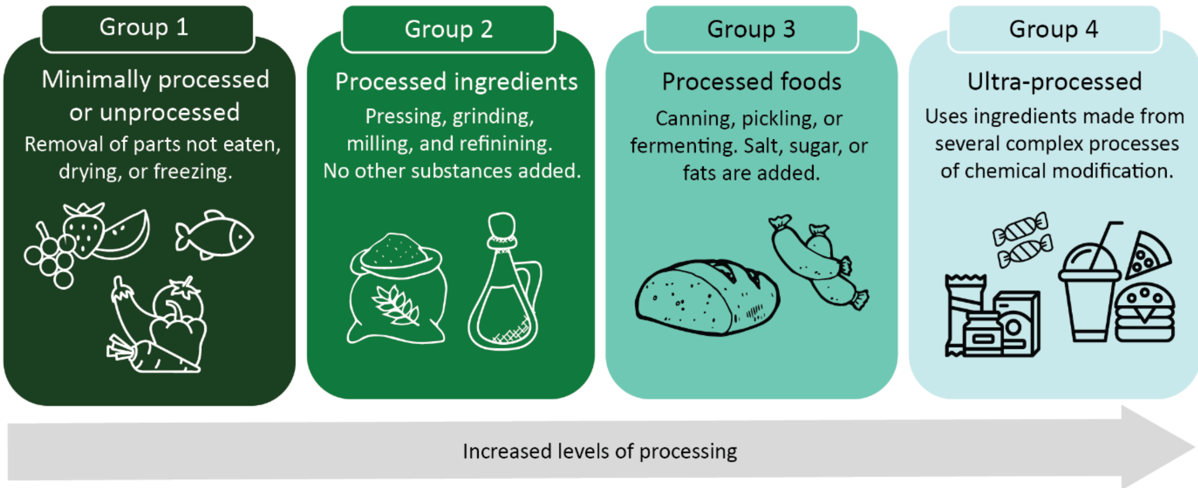

Figure 16: NOVA classification of processed foods. Adapted from Crimarco, et al.[234]

Tensions and trade-offs in the processing and manufacturing of food

There are many trade-offs that occur with advances in food processing and manufacturing. Packaging improves durability of a product, extends shelf life and can also be a food safety requirement, but the current use of plastics contributes to a global waste issue (see section 1.1, *Rethinking plastics in Aotearoa New Zealand*). Food processing may preserve or enable the addition of vitamins and minerals necessary for human nutrition, but many UPFs have been widely criticised for their poor nutritional quality and are hypothesised to have contributed to increasing obesity prevalence.[235] Processed food can be convenient but can also have less nutritional value.[236] There is some evidence that suggests people most reliant on convenience food generate the most waste, and hints at links between the consumption of UPF with poorer mental wellbeing.[237,238] These relationships do not necessarily suggest that convenience and UPFs cause high waste and poorer mental wellbeing respectively; it is plausible that people turn to convenience and UPF at times of their life when minimising waste is more challenging or their mental health is poorer.

Fresh foods are generally more nutritious, but are not always a practical option. Large-scale processing can be an efficient mechanism to meet consumer demand for convenient, delicious, and varied food. However, processing increases the use of resources like water and energy and so if food is lost or wasted, so are these resources. Processing and manufacturing can potentially prevent waste by increasing the shelf life of fresh foods but also contribute to waste being generated, for example, through the removal of constituent parts like tomato skin, seeds, and pulp to make tomato juice (see case study 1).

Aotearoa produces high-quality and safe food, which is assessed to meet high standards and exported globally. Processors and manufacturers are obliged to produce safe and suitable food that won't make people sick, as well as being suitable for intended use with labelling requirements around nutrition, dates, and ingredients under the *Food Act 2014.*[137] Meeting quality specifications and food safety requirements when producing a food product can contribute to FLW during processing and manufacturing (see sections 2.1.2 and 3.1.3). Quality control needs to be carried out to ensure food meets safety and quality standards, but also typically results in some product being destroyed in the process of testing, and further loss if products do not meet specifications. Ethical responsibilities or environmental protection can sometimes work against business' profit motive – for example, pork produced in New Zealand is more expensive due to high animal welfare obligations.[239] This potential trade-off is addressed by requirements around food safety, but there are no similar requirements on reporting or preventing FLW. Figure 17 describes some tensions and trade-offs when attempting to reduce FLW in processing and manufacturing, though they do not always have to be in opposition and could be aligned. This chapter explores the potential areas to prevent FLW in the processing and manufacturing sector, while acknowledging that cost is a significant factor in decision making in any company, and there are sometimes trade-offs manufacturers must make.

Figure 17: Tensions and trade-offs in FLW prevention during production and manufacturing; they do not always have to be in opposition and could align.

4.1 Understanding FLW during processing and manufacturing

Processing and manufacturing are important for preventing food from falling to lower levels of the food recovery hierarchy since much of the purpose of processing is to keep fresh food edible for a longer time. FLW within processing and manufacturing can be broadly understood as either 'unavoidable' loss, or 'avoidable' loss. Unavoidable loss in food processing and manufacturing, in general, is the expected waste quantities used for foreseeable circumstances including by-products (edible and inedible); retention samples for quality control; cleaning or testing machinery; testing to meet product specifications or terms of trade or financially viable returns; and research and development for new products. Avoidable loss, in contrast, is a result of errors or inefficiencies, such as damage to equipment or human errors[240-242] including difficulties in planning inventory and matching production with demand.[243] Figure 18 shows the main causes of FLW in processing and manufacturing facilities. Appropriate strategies for prevention will be specific to subsectors or individual companies and depend significantly on factors like firm size, processing methods, and resource availability, all of which are highly variable within the food industry.

Appropriate strategies for prevention will be specific to subsectors or individual companies and depend significantly on factors like firm size, processing methods, and resource availability...

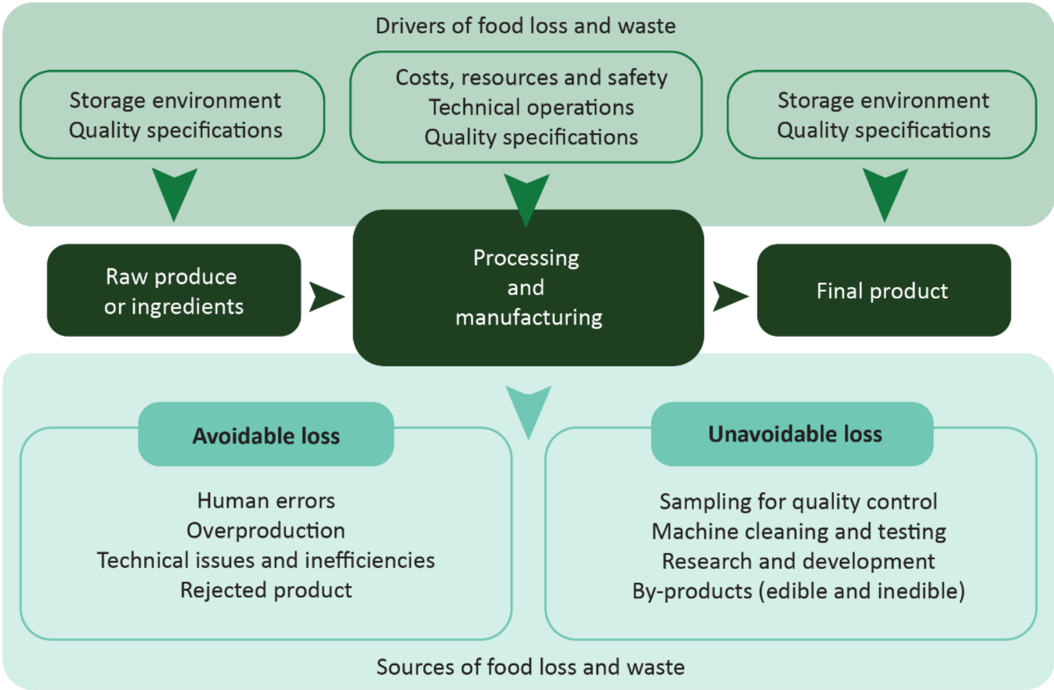

Figure 18: Causes of FLW in processing and manufacturing. Adapted from Raak, et al.[240]

4.1.1 Processing and manufacturing in New Zealand

Major processing companies based in New Zealand include: Fonterra, Sanford, Talley's, Tegel Foods, New Zealand King Salmon, and T&G*. International companies such as McCain, Watties, and Nestlé also manufacture in New Zealand (see figure 19). These companies purchase raw produce or ingredients from farmers or other suppliers and manufacture food products to be sold by retailers locally or internationally. The dairy sector in Aotearoa (see section 3.1.1) is dominated by Fonterra, which is estimated to have 80% of the market share of milk processing.[244] In meat processing (see section 3.1.2), four major processors – Alliance Group, ANZCO Foods, Silver Fern Farms, and AFFCO New Zealand – account for almost 85% of all industry revenue.[245]

* Formerly called Turners and Growers, we use the name T&G to include T&G Global as well as any other T&G operations.

Figure 19: A sample of processors and manufacturers operating in New Zealand (i.e. by no means a complete list).[246] Some companies may also produce food that fits into more than one category. Adapted from a 2012 Coriolis report, Driving growth in the processed foods sector.[247]

A large percentage of food processing and manufacturing in Aotearoa involves dairy and meat, a significant proportion of which is exported to overseas markets (see figure 20). Currently, New Zealand exports mainly minimally processed foods including beef, kiwifruit, and apples but also processed dairy products such as milk powder, butter, and cheese.[247] The packaged food market has been growing and is expected to continue to grow globally, and currently a large proportion of our processed foods are imported from overseas.[246] Processing can create high-value goods with high export prices such as infant formula and nutraceuticals, and is therefore of significance to our economy; this makes it an important domain in reducing FLW.[247]

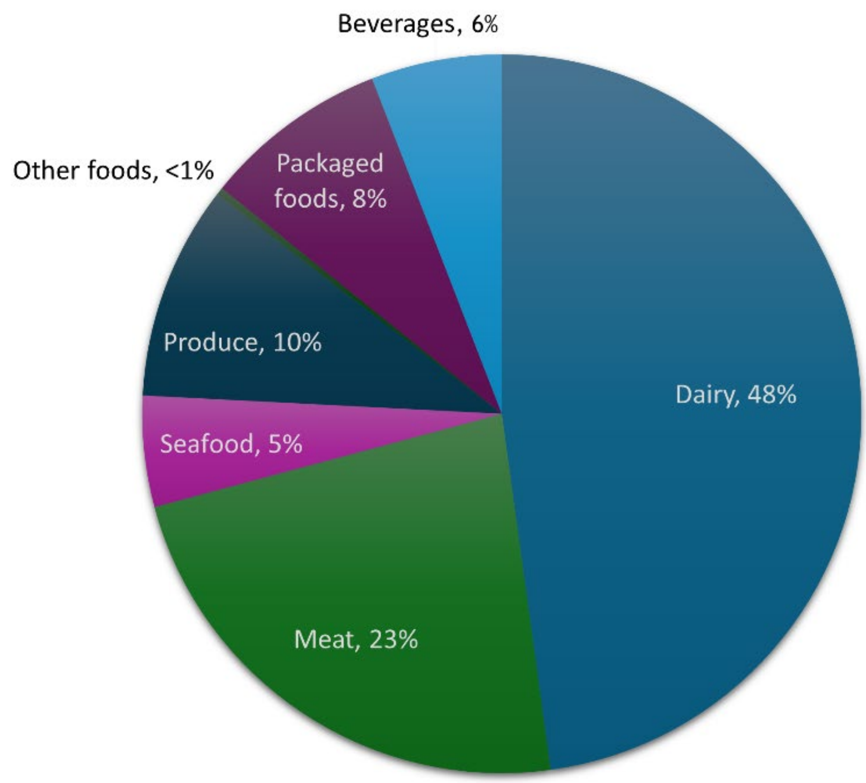

Figure 20: New Zealand food and beverage (including alcohol) export values in 2018. Data source: Coriolis report Investor's Guide to the New Zealand Food and Beverage Industry.[248]

4.1.2 What causes food loss during processing and manufacturing?

food loss during processing and manufacturing occurs for a variety of reasons. FLW in processing can be high due to removal of the parts of food that are inedible or typically not eaten, for example the husk and cob of corn or the head, bones, and offal of animals; by-products arising during processing are a major part of built-in waste. In common with other parts of the supply chain, it is difficult to accurately predict demand for a product, so overproduction and subsequently excess stock is common, creating avoidable FLW particularly in products with a short shelf life.[243]

> … it is difficult to accurately predict demand for a product, so overproduction and subsequently excess stock is common, creating avoidable FLW particularly in products with a short shelf life.

Human and machine errors also create loss at this stage of the food supply chain. Incorrect orders and poor inventory management are significant contributors.[241,242] Poor practice around storage, handling, or transportation can result in damage to products including contamination, insect infestations, mould, and deterioration.[249,250] FLW can occur due to technical faults or machine transitions occasionally resulting in incorrect manufacturing or contamination.[251] For example, on machine start up, standardised volumes may not be met, leading to unmet product specifications; or changes to formulation can result in temporary contamination. Equipment or machine failures can also result in deformed or inaccurate products or packaging.[241,242]

Safety standards and quality specifications can also create loss. Part of this is unavoidable, as safety standards and quality control can require product samples that are removed from the supply chain. A product not meeting the specifications set by the manufacturer or purchaser can result in rejected and wasted stock.[241] Similarly, developing and trialling new products can result in food loss due to removing products for calibration and testing, or failure to meet specifications. Products that do not meet specifications can sometimes be remanufactured or sold to secondary markets (often at other levels of the hierarchy like food rescue (section 2 in *Food rescue in 2022: Where to from here?*) and upcycling (section 3 in *Beyond the bin: Capturing value from food waste*)).

Specifications set by the manufacturer may be driven by large buyers with purchasing power, industry standards, and/or expectations of wholesalers or purchasers further downstream.[252] The setting of specifications could also be influenced by bargaining power and the agreed upon terms of trade around ownership and liability.[107] Attempts to exert market power through practices like stockpiling to reduce supply, or promotions to influence demand and pricing, can lead to FLW.[241]

Specifications set by the manufacturer may be driven by large buyers with purchasing power, industry standards, and/or expectations of wholesalers or purchasers further downstream.

As an example of the effect of specifications on FLW during processing, milk bought by the dairy company Fonterra is collected by tankers from farmers to deliver to processing plants where it is tested for quality, before processing (i.e. pasteurisation) and manufacturing into dairy products (for example, cream and yogurt).[253] Test sampling occurs throughout, with samples that fail the test resulting in an entire tanker (25,000 litres) being thrown away.[253] Products for export must meet food safety requirements under the *Food Standards Code* as well as export eligibility requirements and other extra requirements from overseas markets. Non-conformance could mean refused entry by the government of the destination country, which might result in waste, unless the product has not been opened or changed and can be re-exported or resold domestically.[254,255]

4.1.3 We need data to map FLW in food processing and manufacturing

Using a model based on landfill data, the wider commercial and industrial sector in Aotearoa was estimated to have generated over 103,000 tonnes of FLW in 2011,[256] which is equivalent to approximately 16% of total FLW. This figure is similar to international estimates with Australia in 2023 reporting 17%,[257] Germany in 2021 reporting 18%,[258] and Japan in 2011 reporting 20% of total FLW occurring in processing and manufacturing.[259] In contrast, some reports from the EU, UK, and Italy estimate that as much as 30%-55% of FLW occurs in the manufacturing stage.[260] A more recent estimate from 2022 suggests that 2.2 million tonnes per year of FLW is generated from processing in New Zealand,[261] highlighting the variability between measures of FLW due to classification (what is counted as FLW), and quantification (how it is estimated or measured).

In Australia, processing and manufacturing is estimated to have the largest proportion of FLW with 63% of food exiting the supply chain.[57] This high figure is partly due to the inclusion of the loss of inedible parts that may be used in the co-production of animal feed or other materials, for example, the head and offal in meat processing being used for pet food or rendering of tallow for biofuels and soaps, and so does not necessarily reflect loss that is preventable.[*,57] There is a need to establish sufficiently accurate and detailed baseline measurements within individual processors and manufacturers, as well as the overall subsector, to enable clear problem definition. Obtaining relevant and reliable data from producers can be challenging due to the lack of standardised

[*] If data from Australia's National Food Waste Strategy Feasibility Study is limited to disposal destinations (which the study defines as commercial composting, home or on-site composting, anaerobic digestion, waste-to-energy, on farm disposal, landfill, and wastewater treatment), the manufacturing sector accounts for 17% of FLW across the Australian food supply chain (1,276 kilotonnes in the manufacturing sector, of 7,676 kilotonnes across the supply chain).

measurement procedures and mandatory industry disclosure – again related to the difficulty in defining what should be counted as FLW, as well as some documentation not being publicly available.[240,262,263]

Data is scarce making it hard to identify causes of food loss and waste

Definitions of what constitutes FLW likely differ between sectors and manufacturers, making amalgamation of, and comparison between, data sets difficult. Manufacturers may also not share data due to commercial sensitivity. Many manufacturers (particularly small or medium-sized ones) may be unaware how much they are wasting due to a lack of resources for measurement and quantification, especially in the absence of requirements for such measurements.[250] Errors or mistakes that lead to food loss also likely go unrecorded, or are not made publicly available. Insight into the causes of FLW, as well as the extent of FLW within various subsectors, are still unknown, and research specific to New Zealand is lacking.[242] Collated data on the main areas of waste and their quantities within a processing plant would be necessary for identifying opportunities for prevention. Figure 21 shows an example of data on loss areas by cost and volume for a convenience food manufacturer in the UK.[243] The relative importance of different types of FLW will be specific to this example of a convenience food manufacturer, likely UPFs, and will be vastly different from a processor of a minimally processed food such as meat or processed foods like canned tomatoes, which may have higher amounts of by-product or trim. This example highlights the importance and usefulness of detailed data for quantifying FLW, as well as the potential for the emergence of different patterns using different units of measurements (for example, costs versus volumes). How we define and use the data can determine the story we tell.

Definitions of what constitutes FLW likely differ between sectors and manufacturers, making amalgamation of, and comparison between, data sets difficult.

How we define and use the data can determine the story we tell.

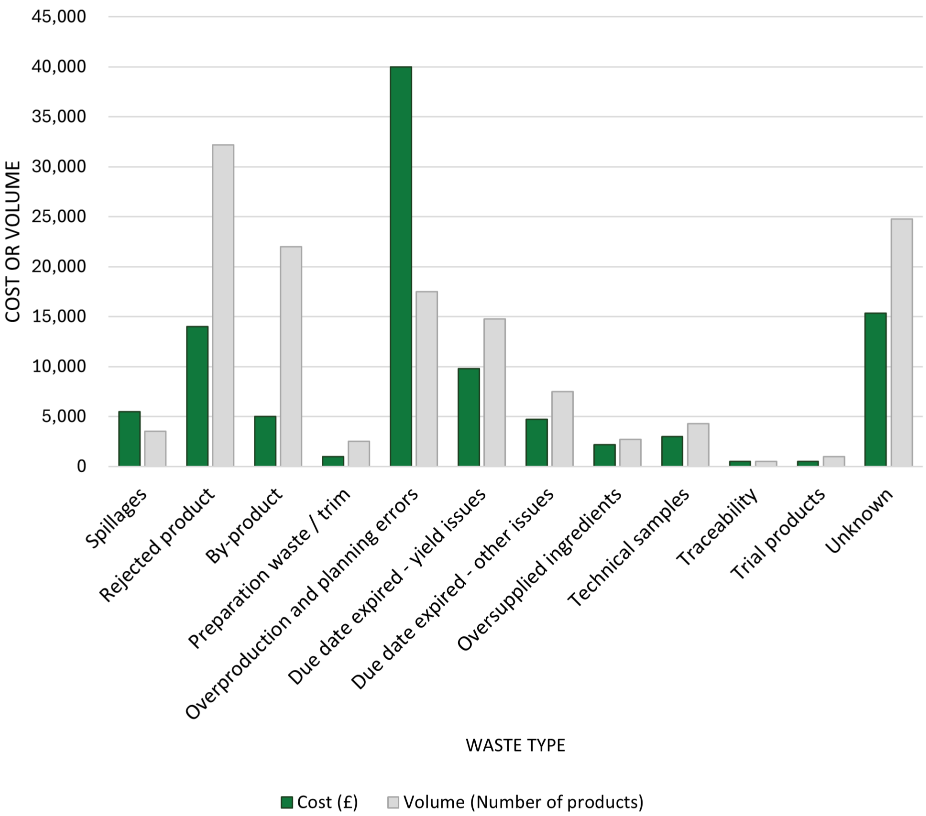

Figure 21: Example of food production food loss data from a UK convenience food manufacturer over a one month period. Adapted from Darlington et al.[243] Units indicate number of products.

4.2 How can we prevent FLW during processing and manufacturing?

Processing and manufacturing companies have commercial interest in reducing or upcycling waste as it contributes to lower spending on raw materials and could increase profit margins. Some loss may be classified as unavoidable by-product and may potentially be valorised through upcycling or nutrient recovery. Sealord, for example, produces fish oil and fishmeal, which in turn are used in a variety of other products.[264] Section 2 of *Food rescue in 2022: Where to from here?* discusses opportunities to redistribute food through the food rescue sector in Aotearoa and section 3 of *Beyond the bin: Capturing value from food waste* discusses processing techniques to capture value from FLW such as through the upcycling of ingredients that would have been discarded or underused.

As valuable as these approaches are, they do not prevent FLW at source, and can contribute to a view that FLW is minimal because it is used in other products. The food recovery hierarchy (see figure 1) needs to be applied with nuance as some FLW is not preventable and different sectors have different circumstances (see section 5 of *Food waste: A global and local problem*). In general, the use of the entire resource in food production, for example, using wheat bran and wheat germ (by-products of flour production) in products for human consumption, such as breakfast cereal, is ideal.

> The food recovery hierarchy needs to be applied with nuance as some FLW is not preventable and different sectors have different circumstances.

A 2021 study in Germany estimated that 10%-55% of FLW was preventable during processing,[258] but more data and information around categories, quantities, and areas of FLW in New Zealand will be needed to help businesses make decisions and optimise processes to prevent FLW. The sections below will explore how business strategies, technological interventions – particularly in preservation techniques and digitalisation – and policy levers can provide solutions to prevent FLW.

Food manufacturers could take a range of potential actions that impact upon FLW at different levels of the supply chain; examples of these are shown in table 5. However, monitoring and measurement across the manufacturing process is a necessary first step to understand where loss is occurring and will allow for strategies, interventions, and mitigation plans to be designed and implemented (see section 2.2). Collaboration across sectors and subsectors also need to be facilitated,[109] with more frequent communication (between suppliers and retailers, for example), updates, and audits that can also help with better information and planning (see section 2.2.6).[251]

…monitoring and measurement across the manufacturing process is a necessary first step to understand where loss is occurring and will allow for strategies, interventions, and mitigation plans to be designed and implemented.

Table 5: Actions by manufacturers that can impact FLW up and down the supply chain.[258] Abbreviations: FLW = food loss and waste.

Actions by manufacturers	**Where will FLW be prevented?**
Check to see if specifications increase supplier's FLW (for example, through supplier audits).[191]	Suppliers.
Communication and cooperation with supply chain network for planning.[265,266]	
Monitor orders and quality with transparency.[267,268]	
Design better packaging for protection and shelf life.[269,270,271]	Internal organisation.
Develop and implement systems for measurement and monitoring.[57]	
Improve planning for processing times and batch sizes.[272]	
Make sure FLW is a part of business culture, goals, and strategy.[243,273]	
Proper handling and storage of materials.[90]	
Train employees around best practices for preventing contamination and machine maintenance.[274,275]	
Communication and coordination around demand forecasting (including promotions).[276,204]	Distributors/purchasers.
Ensure proper transport and storage conditions.[277]	
Reevaluate optimal or necessary specifications such as labelling, quality, and package sizing.[241,252]	
Provide clear information around storage instructions and meaning of date labels.[257]	Consumers.
Conduct education, outreach, or public communication campaigns.[278]	Other stakeholders.
Sector collaboration on data and best practices.[61,109]	

There is a lack of aggregated evidence on the comparative effectiveness of different interventions

There are many ideas, options, and strategies for FLW prevention during processing and manufacturing; however, there is still a lack of significant evidence around the effectiveness of different interventions. Interventions are also typically case study specific, making it difficult to compare effectiveness or transfer learnings. Choosing the most effective interventions is challenging, and a lack of substantial evidence can prevent organisations from taking a risk to change processes.[279] Evidence on the outcomes of specific interventions ideally needs to be able to be aggregated for transferability within and possibly across subsectors.

4.2.1 What business strategies could be considered?

The size and scale of business operations, as well as costs and the specific situation, will greatly impact a processor or manufacturer's capabilities to adopt changes to address FLW. However, there are two general approaches processors and manufacturers can apply in preventing FLW. The first is optimising existing internal processes, for example, by developing protocols around preventing FLW such as reworking products that don't meet specifications; and the second is increasing the market value of otherwise wasted food, for example, by prolonging the shelf life to increase the value of a product, or enabling secondary markets to sell products that have minor imperfections such as misprinted labels.[280]

The use of by-products to create new products, for example, through upcycling has been covered in the previous report of this series (see section 3 of *Beyond the bin: Capturing value from food loss and food waste*). Both optimisation and valorisation approaches can involve low-level operational changes and high-level strategy changes to business practices. In our discussions while carrying out research for this report, we heard the importance of change being driven through top-down leadership.

Collaborative practices could aid in the prevention of FLW

Increased exchange and sharing of information, both internally and externally, can support better planning, decision making, and the development of best practice. Better data being shared between suppliers and purchasers can aid in order prediction, inventory management and equipment scheduling. Collaborative, cross-sector approaches can also be used to reduce human error, including through education and training.[273] However, collaboration and competition can be in tension.[273] Data may be commercially sensitive, and within sector collaboration must avoid breaching anti-competition laws.

Collaborative, sector-wide approaches, particularly in data collection practices, need to be developed.[109] There is a need for more collaborative structures and open-source information for the synchronisation of organisations working in the same sector. Sharing data within subsectors can also support establishing sector-wide FLW measures and best practice guidelines as well as national industry growth. Third party data infrastructure and platforms like the Global Data Synchronisation Network (GDSN) by GS1 New Zealand (see box 4) provide a means for organisations to promote their product, choose what information to share and subscribe to promotions or information from suppliers. Also, there are sector specific networks, which work to develop their own data sharing protocols, for example, Trust Alliance New Zealand's digital farm environment plan project and digital wallet project (see box 3).

Box 4: Global Data Synchronisation Network

Better data systems across the supply chain can enable better transparency, risk management and efficiency to reduce FLW through better quality assurance, shorter wait times at choke points and less spoilage.[281] The Global Data Synchronisation Network (GDSN) is the world's largest real time product data network, developed by GS1 New Zealand, to support high-quality, standardised data from authoritative sources.[282]

Manufacturers sell to hundreds of retailers and distributors, so accurate, up-to-date data is important for the smooth movement of products. Examples of relevant data include logistical, shipping, and regulatory information. The GDSN makes it possible for any company and any product to upload and access information to trade products on local and international markets.[281]

The GDSN uses data pools to synchronise product information for trading partners. Data pools are interconnected and interoperable through a global registry and uses a publish/subscribe model,[282] where suppliers publish product information to a source data pool and a recipient's data pool synchronises relevant updates based on subscription.[283] This is one example of a data network for products which can facilitate efficiency through digitalisation of the supply chain.

Food loss and waste should be a part of key performance indicators and high-level strategy

A sustainability focused strategy can enhance environmental and economic performance through more efficient exchange of materials and by-products, for example, if the waste from one process becomes input to another. It can also promote innovation and new business opportunities as industry and consumers shift in attitudes.[284] Within an organisation, strategy must be aligned with specific targets or key performance indicators (KPIs).[284] It is hard to "manage what you can't measure", and having quantifiable measurement towards a desired outcome is necessary to effectively manage progress.[285] Capturing data to understand the baseline around inventory, manufacturing processes, and loss or waste is necessary to set targets, and budget must be available for operational change.

New business or contract models could be explored

The lean manufacturing model focuses on mapping value-adding steps, improving connections and flows in a system (such as by prioritising quick changeovers), and continual refinement of processes to cut down costs and reduce waste in production.[286] It has been popular in mass production industries, originating from the automotive industry.[286] In a case study of a UK vegetarian and vegan meal products manufacturer applying lean techniques, food losses in mixing, weighing, packing, and freezing were reduced in the range of hundreds of kilograms over a three month period.[287]

Adopting loss prevention strategies can be a part of a greater transformation of an organisation's existing business model towards sustainability, circular economy approaches, social enterprise, or industrial symbiosis, which explores how a company operates within its larger ecosystem (see section 1.2).[284,288,289] This could also potentially be extended to business relationships and incorporated in contract models or terms,[107] such as in procurement processes, including evaluation of bids for contracts, or sharing responsibility and carrying out due diligence for sustainable practices with suppliers and sub-suppliers.[246] Digitalisation can also enable this, as exemplified by CiRCLR, which is a business-to-business platform that helps companies turn potential FLW into new revenue streams for businesses (see section 2.2.2).[290] The growth in consumer appetite for environmentally and socially responsible goods also provides a solid business case.[291]

4.2.2 What technological interventions are available?

New technological methods could enable innovative new products that create a competitive advantage and increase profits. For example, in processing milk for cheese processing, whey is created as a by-product, which is popularly marketed as a fitness supplement.[*]

Technological innovations in food science can aid in reducing food spoilage. Short shelf life products are at a greater risk of being wasted, so innovations in processing technology that increase shelf life can support the reduction of waste. Packaging technologies and labelling can also increase shelf life of food products as well as mitigate the use of plastics (see sections 3 and 4, *Rethinking plastics in Aotearoa New Zealand*), prevent damage to the product, provide information for better storage, and shape the way consumers interact with food products. Examples of these types of technologies that increase a product's shelf life are described in table 6 and are one area of action processors and manufacturers could consider for preventing FLW at other points in the supply chain.

Meeting safety requirements and product specifications are a major trade-off against FLW generation; there is a need for manufacturers to optimise production while maintaining quality. Automated digital systems can increase efficiency, reduce the risk of human error, as well as provide data measurement, control, and oversight. Overall system design for monitoring, measurement, and communication can also be aided by digital technological innovations to increase efficiency. Examples of such hardware and software technologies and how they can prevent FLW are described in table 7.[292,267] Technological interventions sometimes are not implemented due to accessibility, costs, and market access requirements – where some markets may have specifications on packaging, or regulations on technologies that impact the food product directly.[292,267]

Food processing prevents FLW

Commercial food processing techniques typically act by inhibiting the growth of microorganisms (for example, freezing, drying, fermenting), inactivating microorganisms (for example, pasteurisation, irradiation) or restricting the access of microorganisms to the food product (for example, packaging).[293] The development of new food processing techniques not only prevents spoilage or increases the variety of products but can also aid in maintaining nutritional values and increasing the quality and value of food products.[294] For example, expanding the life span of bread has been taking place for thousands of years through fermentation with lactic acid bacteria to increase acidity for antifungal activity (in the case of sourdough), and in modern times chemical preservatives (for example, calcium propionate) are commonly added to breads to extend shelf life.[295] Table 6 describes state of the art food processing techniques in the context of FLW.

[*] Whey is also an example of the sometimes blurry boundaries between different stages of the food recovery hierarchy – in *Beyond the bin: Capturing value from food loss and waste* we used whey as an example of an upcycled product.

Table 6: Current and emerging food processing and packaging technologies that help to extend the shelf life of foods. Abbreviations: MPa = megapascals, nm= nanometres, PEF = pulsed electric field, UV = ultraviolet light, UV-C = short wavelength ultraviolet light.

Technique/Technology	Description	Example(s) of use	State of use
Active packaging.	Packaging with added materials such as antioxidant or antimicrobial compounds that interact with the product or product environment to extend shelf life, positively impact food quality and safety, and deter spoilage.	Nano-pack[296] was an EU funded project that developed an antimicrobial flexible plastic food film shown to extend the shelf life of breads, cheeses, and cherries.[297]	Some adoption.
Aseptic processing.	The controlled sterilisation of a processing facility where the sterile food product is in a sterile package, which is then hermetically sealed so no air can pass in or out.[298]	This process is mainly used for liquid-based foods like milk, juices, yoghurts, salad dressings, baby foods, soups, and desserts.	Widespread use.
Chemical preservatives.	Added compounds, which help extend shelf life by inhibiting oxidation, browning, or enzymatic reactions and ensure safety by inhibiting or killing microorganisms. Typically, an acid-sorbate, benzoate, sulfite, or nitrite; well lactic, citric, and acetic acids are common as well. Parabens, sulfur dioxide and sulfites are also used for their antimicrobial activity, as well as antioxidants.[299]	Lactic acid is commonly added to fermented meat and dairy products while citric acid can be found in jams, sauces, cheeses, baked goods, and canned vegetables.[299]	Widespread use.
Cold plasma.	Applying partially or totally ionised plasma gas, which carries chemically reactive species including photons, ions, free electrons, and atoms at ambient temperature, is a promising method for attaining microbiological safety in temperature-sensitive food.[300,301]	Has shown to be an effective decontaminant for fruits and vegetables, and potential meat preservative but has not yet been applied commercially.[301]	Research and development.
Ethylene-removing packaging.	Ethylene is formed during ripening, bruising or disease of produce via microorganisms. Ethylene removing packaging is a form of active packaging which reduces ethylene concentration surrounding produce through adsorption, absorption or chemical reactions during transportation and retail.[302]	Ethylene adsorption packaging, which covers pallets is used in the transportation of fruits and vegetables to slow ripening.[303]	Some adoption.
Flash pasteurisation.	Also known as high-temperature, short-time pasteurisation, which heats beverages to 72 °C- 80 °C for 15-30 seconds allowing microbial inactivation to occur, followed by rapid cooling to 4 °C- 5 °C.[300]	Typically used to extend the shelf life of milk, but also used in beer.[300]	Widespread use.

Technique/Technology	Description	Example(s) of use	State of use
Freeze-drying.	Also known as lyophilisation, freeze-drying involves the freezing of the product, which inhibits microbiological processes, drying through ice sublimation (most often at reduced pressure), and then desorption drying (drying the product to the required final humidity).[304]	Fruits and vegetables are the most common foods to be freeze-dried, as well as confectionery and desserts.	Widespread use.
High pressure processing.	The application of high mechanical pressure (100-800 MPa) for seconds to minutes, which inactivates microorganisms and denatures enzymes with minimal effect on food quality and nutrition.[298]	Deli meats, dips, seafoods, sauces, beverages, jams, pet foods, baby foods, fruits, and vegetables products typically undergo high pressure processing.[305]	Widespread use.
Intelligent packaging.	Chemical agents or sensors that monitor the state of the product or environment and provide information that indicates food quality to help consumers decide whether to purchase or eat.[271]	Colourimetric indicators (which changes colour due to enzymatic or chemical interactions) are used to indicate the freshness of fish and meat products.[271]	Some adoption.
Modified atmosphere packaging.	Providing the optimum conditions for a food product through modifying or altering the atmosphere inside a package, slowing the growth of microorganisms through preventing chemical and biochemical reactions.[298] Also includes vacuum packaging.	Common foods that have modified atmosphere or vacuum packaging include salads, fresh pastas, meat, seafood, cheeses, and bakery products.[306]	Widespread use.
PEF Technology.	Involves the application of high voltage short electric pulses, which inactivate enzymes and microorganisms. This also can be used to restore quality or change properties of produce.[307]	There is some commercial use in juices and smoothies. Also, in wine making and potato processing – so they have a more uniform colour and absorb less oil during frying (see case study 2, *Beyond the bin: Capturing value from food waste*).	Research and development.
Ultrasonication.	Ultrasound application can be used as a preservation method through microbial inactivation and in the analysis or change of physico-chemical compositions of food.[308]	Used with fruits and vegetables, cereals, honey, and dairy products. Also, for the tenderisation of meat products.[308]	Widespread use.
UV-C radiation.	UV irradiation in the wavelength range of (200-280 nm) disrupts the genetic material of microorganisms, also enables the preservation of nutrients.	Can be used to increase the shelf life of milk, breads, fruits, and vegetables.	Some adoption.

Improved packaging design and innovations can prevent food loss and waste

Packaging design and packaging innovations like active packaging can prevent FLW both at the at the processing and manufacturing stage, as well as further downstream in the supply chain.

Improved packaging design can prevent food being lost or wasted due to damage, as well as enhance its shelf life. This can be achieved in a number of ways: on-package information to provide consumers with instructions regarding ideal storage conditions; resealable packaging can prevent exposure to air or moisture; flexible and transparent packaging can increase accessibility and visibility; smaller or more varied packaging sizes can make it easier for consumers to purchase the right amount of food.[309] It is also critical for food preservation and safety.[310]

Active packaging can embed compounds like antioxidants and antimicrobial agents to combat degradation, prolonging the quality and safety of food products, while intelligent packaging uses sensors and indicators that react to microbiological or environmental changes like temperature or pH level, to monitor food quality and safety.[270,311] Active and intelligent packaging (see figure 22) can help consumers make decisions on food disposal as more accurate indicators of quality or safety rather than date labels (see box 9). Finally, the addition of radio frequency identification (RFID) tags and 2D barcodes such as quick response (QR) codes, can enable real time gathering and/or sharing of more information about products to various stakeholders across the supply chain, including manufacturing date and batch number, which could also potentially be useful for tracking or food recalls.[312,313]

Active and intelligent packaging can help consumers make decisions on food disposal as more accurate indicators of quality or safety rather than date labels...

Figure 22: Examples of intelligent packaging systems (a) Temperature indicator; (b) ripeSense indicator; (c) Freshness indicator; (d) Freshness indicator. Image credit: Yan et al.[311]

Though there is an inherent tension between reducing food waste through packaging and the increased waste production from packaging, this could potentially be mitigated through innovations at the systems level or by new materials technologies such as bio-based plastics (see sections 3 and 4 of *Rethinking Plastics in Aotearoa New Zealand*). Life cycle analysis has shown that the environmental footprint of FLW can sometimes be greater than the impact of the packaging itself.[314]

Technological solutions supporting data and management can aid food loss and waste prevention

Analysing data for more effective decision making in food processing and manufacturing can be aided through recent advances in digitalisation (see table 7). Aggregate planning and scheduling have always been necessary to be able to optimise resources and production. Overproduction and FLW typically occurs when planning or demand forecasting is poor.[272,276] Demand forecasting models can be used to support production planning and inventory management, with recent developments in big data, machine learning (ML) and AI improving their accuracy.[315,316] IoT monitoring systems and digital twin technology, which provides virtual simulations and data dashboards, can capture data during manufacturing in real time and even make it available to other stakeholders such as suppliers, regulators, or purchasers.[317] The direct monitoring and digitalisation of collecting FLW information through IoT architectures also seems to be a promising intervention (in one case, a ready meal factory reduced waste by 60.7%).[318] A food processor could also use improved demand forecasting technology to combine data from diverse sources, like social media trends or weather, to understand potential changes in demand or risks to supply and make real time decisions in response to events such as severe weather events (see case study 9).[319]

Enterprise resource planning (ERP) software is also commonly used to help analyse shelf life, track orders, prevent cross-contamination, avoid overstocking and more easily manage an inventory.[250] Recent developments in advanced planning and scheduling (APS) systems can integrate supply management, production scheduling, order processing, and demand forecasting for integrated planning and coordination.[320] APS systems can be useful for adapting to fluctuating demand, manufacturing processes that make multiple products, and making to order rather than making to stock. However, SMEs are less likely to use ERP software or advanced planning systems and are also typically less able to cope with disturbances, rush orders and breakdowns.[321] The use of barcode and/or RFID technology (see box 5), which could be combined with sensors for environmental monitoring is also being researched widely for application in the food industry, likely due to its low cost, accessibility, and ease of integration into existing systems.[271,312,322] These digitalisation solutions for data and management enable better visibility and operational improvements to support better planning and decision making.

APS systems can be useful for adapting to fluctuating demand, manufacturing processes that make multiple products, and making to order rather than making to stock.

Table 7: Summary of technologies that could be used in processing and manufacturing to support the prevention of FLW. These technologies are non-exhaustive and may be combined and developed in a myriad of ways by designers and engineers for specific use cases and system integration. General implementation considerations for all technologies are costs, integration with existing infrastructure, privacy and security, and a need for skilled people and training. Abbreviations: 1D = one dimensional, 2D= two dimensional, 3D = three dimensional, AI = artificial intelligence, APS = advanced planning and scheduling, AR = augmented reality, ERP = enterprise resource planning, FLW = food loss and waste, IoT = internet of things, ML = machine learning, RFID = radio-frequency identification, UoA = University of Auckland, VR = virtual reality.

Technology	Description	Potential impact on FLW	Example	Considerations
AR and VR.	Computer-generated models or environments that alter a user's perception through visual immersion or overlays.	AR and VR could be used to help train staff in processing and handling. They could also provide access to, and present data to enable better decision making.	A VR environment allows staff to interactively and step-by-step be guided through alerts and maintenance operations of an industrial ice cream machine.[323]	Early adoption. AR and VR hardware is commercially available, but software development for useful applications in manufacturing is needed.
APS systems.	Software algorithms or models that support the allocation of resources and materials to maximise production capability.[324]	APS systems can help with the planning and optimisation of production to meet demand and prevent overproduction or order errors.	A poultry processor in the US, Koch Foods, implemented an APS system to streamline operations through better planning and scheduling resulting in reduced change overs and packaging problems.[309]	Widely available. There is a large range of commercially available APS systems.
AI.	Simulations and software that can perform complex tasks through learning.	AI can be embedded in software systems to help analyse data and make suggestions and predictions for better decision making.	AI can be used to optimise and control the drying process of fruits and vegetables using physical fields (e.g. infrared, microwave), for better efficiency as well as improve the quality of dried products.[325]	Early adoption. Generative AI models are now easily accessible. Neural network and deep learning models have had recent exponential breakthroughs.
Big data.	Large amounts of data and information for analytics, evaluation, or prediction.	Data can be collected throughout the food supply chain to enable better measurement and understanding of where and how loss occurs.	Anticipatory shipping can use historical order and customer data to predict future orders and ensure products are located at the nearest distribution centres to optimise logistics.[326]	Significant adoption. Cloud-based storage systems are relatively accessible and cheap. Big data is the backbone of other technologies like AI and ML.
Blockchain.	Distributed, decentralised database mechanism for	Blockchain could be used to enable fast, secure	IBM Food Trust is a blockchain-based platform to track food	Early adoption. Blockchain technology has relatively high

Technology	Description	Potential impact on FLW	Example	Considerations
	secure transactions across a network.	transactions. For example, smart contracts.[327]	products from farm to table, enabling suppliers and retailers to identify any safety or quality issues quickly.[85]	computational and network requirements.
Computer vision.	Algorithms or software, typically using neural network models, which enables computers to interpret and identify images or videos.	Computer vision could help identify and sort food products by visual qualities such as colour and texture for improved quality control.	Compac Sorting uses computer vision capabilities to improve defect detection and categorisation for cherry sorting and grading.[209]	Early adoption. There have been significant developments in computer vision and it is able to be integrated in manufacturing systems.
Digital twin.	Virtual representation of objects, products assets, and processes that can deliver real time structured information through aggregating data across a context.[323,328]	Digital twins could help food processing companies monitor equipment, products, and processes to detect issues early and prevent unplanned waste.	The food manufacturer Mars is deploying digital twins in manufacturing facilities to optimise production, improve margins and reduce FLW.[329]	Early adoption. Digital twins need access to data sources.
Demand forecasting.	The use of analysis and models based on past data to predict future demand for a product.	Demand forecasting could result in more accurate predictions to aid better planning in manufacturing quantities and minimise overproduction.	The use of demand forecasting models in a study of three German bakery chains resulted in a waste reduction of 37%-89%.[330]	Widely available. The accuracy and complexity of demand forecasting models vary.
ERP software.	Integrated system for the management of business processes such as materials, production, inventory, and orders.	ERP software helps manage inventory and orders for better planning and fewer errors.	Spoiler alert[331] is a commercial platform for inventory management, providing data insights and accelerating transactions – particularly for short-dated inventory in the food and beverage industry.	Widely available. There are many business and inventory management software solutions commercially available.
IoT.	Network of devices integrated with sensors and	IoT can provide information to workers to help with	A case study of a ready-meal factory using an IoT system	Widely available. Many actuators, sensors, and devices can now be

Technology	Description	Potential impact on FLW	Example	Considerations
	software to connect and provide data or information.	measuring, monitoring, improve communication and reduce manufacturing errors.	architecture for the capture and digitisation of FLW data in real time showed a 60.7% reduction in FLW.[318]	connected, there is also scope for extension.
ML.	Statistics-based algorithms that learn from patterns in data.	ML algorithms can be used to better predict demand for forecasting.	Hyperspectral imaging with ML to analyse food composition enabling producers to ensure their product meets quality standards non-invasively, identifying issues early and minimising destruction of the product.[332]	Significant adoption. Using ML to analyse big data and create automated systems and do predictive modelling is relatively common.
RFID tags.	A wireless radio system to provide automatic identification and tracking by a reader or scanner.	RFID can help with the tracking and monitoring of items in production and throughout the supply chain.	A RFID system was embedded with non-destructive quality analysis on single units of artisanal Italian cheese for quality and tracing information.[312]	Widely available. RFID technology has been widely used and implemented in a wide range of cases.
2D barcodes.	Encodes information in the horizontal and vertical dimension compared, with traditional 1D barcodes to be read by a camera-based imaging scanner.[333]	2D barcodes can contain information such as serial or lot numbers, manufacturing or expiration dates, and website links.	Woolworths Australia (in collaboration with Hilton Foods and Inghams) trialled 2D barcodes on meat products in August 2019 to improve traceability and stock management.[334]	Widely available. If already using 1D barcodes, GS1 NZ offers 2D barcodes which will still work with traditional scanners.[333]
3D printing.	An additive manufacturing process that involves the layering of material filaments to create a product.	Can be used with edible materials and create food products with customisable shapes, sizes, and nutritional value. Off cuts, trimmings, or by-products, which would otherwise be wasted could be used.[335]	The Creative Design and Additive Manufacturing Lab at the UoA Faculty of Engineering is using chocolate powder or meat waste in 3D printing to create new high-value products.[336]	Early adoption. There is a commercially available 3D printer for chocolate. 3D printing for other food substances like meat or cake or pizza are also in development.[337]

Research and innovation for technological solutions in food processing

There are many areas of research that could contribute to the development of innovative solutions to prevent FLW in processing and manufacturing such as: food science for novel processing techniques; operations research for increases to efficiency; and food science and psychology for improved product and packaging design. For example, flavournomics research, which studies the development of flavour profiles, could reduce FLW by enhancing the taste and quality of food through processing techniques.[338] The application of emerging digital technologies, as well as the integration of data and digital technologies such as through multimodal data fusion to be able to combine multiple data sources will be a key area for innovation in the food sector.[339] Research into quality control requirements and novel quality control tools (for example, spectroscopy, imaging, and modelling) could also prove to be less destructive and require less product than current techniques. Social science research will be able to shed light on the effectiveness of interventions, their impacts, and identify top priorities for implementation.

Box 5: Technology for traceability

Barcodes were first used by the food and grocery sector in 1974 and were quickly adopted in New Zealand in 1981.[340] They are now used ubiquitously on products during transactions and for inventory management. The organisation GS1 New Zealand (see box 4) coordinates universal product codes (known as UPCs) to provide standardised company codes, product codes and check digits (for verification). Manufacturers register with GS1 New Zealand and are assigned a company code to use.[341] 2D barcodes are now offered, which also encompass the data currently used for linear barcodes. 2D barcodes, like QR codes, can be used to store and access more information about a product than traditional barcodes, including batch numbers, serial numbers, manufacturing dates, quality assurance, and more.[313] Also, they can provide a URL for consumer facing web information to link to ingredient lists, expiry dates or even promotions and product reviews.

RFID tags use radio waves to transfer data and can be read at a larger range with multiple tags at once compared to barcodes (which also need to be in the line of sight of a scanner).[341] RFID data can be updated or overwritten, as well as encrypted to make it difficult to replicate and provide security. Tags are usually more durable (for example, waterproof) than printed barcodes, but are also more costly.[313] RFID technology, like barcodes, are therefore also useful for identification and can provide traceability in real time. RFID systems have the potential to combine information in inventory and logistics management, for example, with sensors for monitoring environmental conditions (for example, linking temperature or humidity sensors in storage for safety or spoilage analysis). Barcodes and RFID can be used at single product item level and/or at case or pallet levels, for managing batches, stock rotations and inventory.

The international standard ISO 22005:2007, which covers food traceability, requires that companies keep a record of suppliers and customers, according to a 'one-up, one-down' principle.[322] Developing traceability is important for quality assurance throughout the whole supply chain and can be useful in reducing handling or storage errors. 2D barcodes and RFID tags enable more detailed information to make product recalls more specific so fewer unaffected products are thrown out; they also potentially automate capturing the batch code or expiry date at till for batch tracing and/or delivering alerts or dynamic pricing. 2D barcodes or RFID can also potentially be integrated in the future with AI vision systems.[322]

Case study 9: AI for demand forecasting and production planning in food processing

A global food manufacturer of grains and meat integrated AI technology for demand forecasting and production schedule optimisation. This involved the development of a user interface and platform that integrated ML algorithms for demand forecasting and optimisation algorithms for scheduling. Previously, the company had used a forecasting solution based on a common statistical approach with limited data, which was less useful because it took a long time to generate and resulted in an inflexible schedule that lacked in optimisation capabilities and scenario planning.

Food manufacturing of short shelf life products have the challenges of short lead times, last-minute order changes, and strict regulatory requirements, which sometimes resulted in missed order fulfilment or excess production and FLW. Sales orders arrived at the plant sometimes daily and when orders deviated from the forecast, planners lacked the time to modify the active demand forecasts and production schedules. Weekly demand forecasts would deviate greatly due to highly variable demand, and schedules would take 90 minutes per production line to generate.

The final AI digital solution was able to leverage more data sources to improve forecast accuracy, including historical production schedules, sales order history and demand forecasts, production capacity and manufacturing specifications, and raw materials and finished goods inventory. It was able to generate daily demand plans with forecasts 21 days into the future, as well as generating production schedules for different time horizons (for example, 2, 7, or 14 days) in advance. The new platform was able to generate a demand forecast and schedule more quickly (in 3.5 minutes), with significantly reduced time spent on manual work for scheduling, better transitions, and order fulfilments.[342]

4.2.3 What policy levers should be considered?

There are currently no FLW reporting or reduction related obligations for manufacturers in Aotearoa though there are industry groups beginning this work in a voluntary capacity (most notably, the Kai Commitment). In this sense, we lag behind other countries: in Norway, government ministries and organisations from industry and retail signed an agreement on FLW reduction in 2017 with a shift toward binding law becoming likely;[109] commercial and industrial premises in Singapore have had mandatory waste reporting since 2014 with reporting requirements around FLW coming into effect in this year (2024);[343] and France has had legislation for the food industry to donate food products fit for consumption since 2020.[344] Recently the European Parliament voted to set legally binding FLW reduction targets, with a 20% target for the processing and manufacturing sector.[345] FLW reduction in processing and manufacturing could be incentivised through certification or funding programmes, which promote sustainable business practices or the uptake of research and innovation. Legislative changes such as preventing organics in landfill and changes to food labelling requirements could also be considered in New Zealand to prevent FLW happening at multiple levels of the supply chain.

There are currently no FLW reporting or reduction related obligations for manufacturers in Aotearoa though there are industry groups beginning this work in a voluntary capacity…

Certification programmes for businesses that demonstrate FLW reduction

Corporate and consumer behaviour can be influenced through certification programmes.[7] Examples of this implemented in Aotearoa already include energy star ratings on appliances, or health star ratings on food products. The Eco Choice Aotearoa label[346] is the most directly related independent certification programme and a part of the Global Ecolabelling Network;[347] however, it is not currently applied to food products. A low waste criteria as a part of a food product certification could help consumers make responsible product choices and is shown to have positive influences on trust and attitudes towards products.[348] Sustainability certifications can also grow sales and increase long-term profitability.[349] These can be third party or government endorsed for increased credibility. Internationally, in March 2023, the French Government launched a national 'anti-food waste' label to distinguish the performance of FLW reduction practices by actors across the supply chain;[350,351] and the Danish Government in 2022 announced the development of a climate label for food to promote environmentally friendly food production and help shoppers make socially responsible choices.[352,353]

> A low waste criteria… could help consumers make responsible product choices and is shown to have positive influences on trust and attitudes towards products.

Grant funding or financial incentives for research and innovation and its adoption

There are significant costs associated with the development and acquisition of new technology, which can prevent widescale adoption, particularly in SMEs. Increased investment could support the research and development of innovative practices or products that will also create new economic value. Providing financial incentives such as grants or tax credits for companies that adopt technology and demonstrate FLW reduction could also facilitate innovation in the sector[7] (see section 7).

Reforming date label requirements

In New Zealand, most packaged foods have a date label. Usually manufacturers will include the words 'use by' or 'best before', where use by is indicative of the date when food could become a health risk to eat and best before relates to the food quality. In the case of bread, 'baked for' or 'baked on' may also be used. Labelling standards are set by the Food Standards Authority of Australia and New Zealand (FSANZ)[354] as legislated by the *Food Standards Australia New Zealand Act 1991*.[355] Standard 1.2.5[356] outlines the date information that must be marked on food labels, and states that it is not required if the best before date of the food is two years or more after the date it is determined; special cases and exceptions include infant formula, individual portions of ice cream and small packets of confection such as gum.

Use by dates are set by processors and manufacturers to indicate when food is safe to eat and can be based on laboratory testing of microbial presence, modelling based on earlier studies or static testing where it is stored under 'typical' conditions and sampled periodically for chemical or physical changes.[357] Best before dates are often arbitrary and at the discretion of the manufacturer so may be chosen for business reasons to do with perception of quality rather than safety.[358-361] Deciding whether to utilise use by or best before can therefore be subjective, particularly in products like cheese, milk, treated meats

> Best before dates are often arbitrary and at the discretion of the manufacturer so may be chosen for business reasons to do with perception of quality rather than safety.

and ready meals – which have sometimes used both use by and best before.[362,358] Also, loose goods, for example, tomatoes, have no date of expiry associated with them but when they are packaged will typically have a date label, highlighting the inconsistency within product types (though packaging also can alter shelf life – as discussed previously in section 4.2.2). Food in New Zealand cannot be legally sold past the use by date due to the health risk but can be sold past the best before date.[363] There is some suggestion that consumers dispose of food on the basis of date labels even if it is still good to eat; we explore this in more detail in box 9.

> ...loose goods, for example tomatoes, have no date of expiry associated with them but when they are packaged will typically have a date label, highlighting the inconsistency within product types...

Date labels are also used in inventory management. A manufacturer's decision to put a short or long best before date can affect retail actions. For example, putting a short best before date can result in retailers prioritising selling the product, even though a product with a long best before dates could be considered to have a competitive advantage. Retailers also occasionally discount products near their expiration dates, although this may signal decreasing quality or undesirability and affect brand image for manufacturers.[364]

> A manufacturer's decision to put a short or long best before date can affect retail actions.

Reform of date labelling has been suggested to prevent premature disposal by consumers or sub-optimal inventory management. A survey by the Australian Institute has shown large support (78%) for reforming use by and best before date labelling.[365] Reforms that could occur include: having standardisation within subsectors of food, rephrasing the wording on the labels – instead of best before using 'often good after'; more descriptive dates like 'manufactured on' or 'freeze by'; removing the requirement of (or even banning) best before date labels on food, and rather than having foods exempt from having date labels; and having foods that are required to have only a single type of date label (for example, use by on fresh fish).[365]

> A survey by the Australian Institute has shown large support (78%) for reforming use by and best before date labelling.

In our engagement for this work, we heard directly from food producers and processors as well as academic researchers that best before dates provide specific benefits to some food businesses. In the case of one producer/processor, the best before date was part of their ability to market the product as having a longer shelf life, which they saw as a point of differentiation from their competitors. In another example, the food would deteriorate before it became unsafe to eat, and removing the option of a best before date could lead to customers experiencing a poor quality product, which would reflect badly on the brand. It is clear that the value of best before dates is very context specific.

> It is clear that the value of best before dates is very context specific.

Alternative design options to date labels could be considered, for example, through active and intelligent packaging. Freshness indicators such as Mimica Lab's 'Bump' (see case study 10) have begun to be integrated into retail products, removing the need for date labels to indicate quality or safety. Changes to packaging and label design could also be effective, such as Too Good To Go's label initiative, which is active in 13 countries and has brands pledge to include a 'Look, Smell, Taste, Don't Waste' label (see figure 23).[366] The aim of the label is to prompt the consumer to check the food and use their senses to decide whether to eat something, instead of the best before date.[366]

Figure 23: Too Good To Go food waste label on Nestlé's products in the UK. Image credit: Too Good To Go.[366]

Case study 10: Bump spoilage indicator

Mimica Lab's Bump (see figure 24) is an example of intelligent packaging aiming to reduce food waste by providing an accurate, real time indication of freshness for products like seafood, juice, and smoothies. It is also compatible with a wide range of other fresh food products such as dairy, meat, and seafood. The label uses a temperature-sensitive, plant-based gel as the indicator. When fresh, the label feels smooth and lets the consumer know the product can be consumed, over time the label will feel bumpy to indicate that the product is no longer fresh. Short shelf life foods are most commonly wasted compared to longer shelf life products, especially if it is past the date label.[241,367] Bump acts as an alternative solution to date label system, and aims to reduce household and retail food waste of perishable products.[368]

Figure 24: Bump cap lid. Image credit: Mimica Lab.[368]

Discussions around label changes have been occurring internationally in Europe since the mid-2010s.[369] Adoption of changes to date labels have mainly occurred due to industry led collaborations and third party initiatives like Too Good To Go,[370-372] or by independent supermarkets (in the UK).[373,374] France has led legislative changes to alter wording on date labelling and abolished requirements for long shelf life food including pasta, rice, and coffee.[375,376,377] Table 8 shows recent international changes and trends in date labelling. Empirical studies, post label change, to explore the effectiveness on consumer behaviour and food waste are currently missing.

> France has led legislative changes to alter wording on date labelling and abolished requirements for long shelf life food including pasta, rice, and coffee.

Separate charges or bans for organic waste and landfill

Ideally, FLW would be diverted at higher levels of the food recovery hierarchy with disposal as the last resort. Disposal is currently discouraged in New Zealand through the waste disposal levy, the revenue of which is distributed among city and district councils to carry out waste minimisation, as well as to the contestable Waste Minimisation Fund, for projects that promote or achieve waste minimisation (see section 4, *Beyond the bin: Capturing value from food loss and food waste* for more detail).[378] This could be modified through having separate charges for organic waste or segregating the organic waste being sent to landfill to raise awareness and incentivise manufacturers to prevent FLW. The organic waste can then be recovered for nutrient or energy recovery (see section 4, *Beyond the bin: Capturing value from food loss and food waste*). In Singapore since 2019, commercial and industrial sites have been required to separate their FLW for treatment and reporting; new buildings are also required to have on-site FLW treatment systems.[379] States in the US including California, Massachusetts, and New York also prohibit sending FLW to landfill.[380] Annex 2 provides an overview table of international policies on bans of organics to landfill.

Table 8: Recent international experiences of date label changes.

Geography	Year	Action(s)	Evidence/outcome(s)
Denmark	2019	In collaboration with Too Good to Go, a number of producers such as Arla, Carlsberg, and Unilever used the words '*ofte god efter*' ('often good after') instead of the usual best before.[372,370] Also, food company Danish Crown has a *'se, duft, smag*' ('see, smell, taste') label.[381]	Based on survey results, 70% of respondents reported that they would throw less food away because the new labelling lets them know that it is still edible after the best before date.[382]
EU	2014	Delegates from the Netherlands and Sweden submitted briefings to the European Commission and European Parliament on food waste and best before date labels, suggesting an extension to the list of products that could be exempted from the requirement of a best before date label, including pasta, coffee, and rice; exploring possible actions to support better understanding by consumers of date labels was also suggested.[369]	The most recent version of regulation no 1169/2011 of the European Parliament states that dates of minimum durability, use by, and date of freezing are not required for fresh fruit and vegetables, wine, beverages containing more than 10% volume of alcohol, bakery or pastry goods, vinegar, cooking salt, solid sugar, and confectionery.[383]

Geography	Year	Action(s)	Evidence/outcome(s)
France	2015 2020 2022	The French senate voted to abolish best before label requirements on non-perishable foods such as dried pasta, rice, and sugar.[375] Large organisations and food producers such as the Ministry of Agriculture, Intermarché, Nestlé, Danone and Carrefour, on an initiative led by Danish organisation Too Good To Go, developed and signed an action plan to communicate more clearly about how long products can be safe to consume, including improving use by and best before date labels.[371] A government ministry decree published that two phrases will be added to the current best before labels in France: '*pour une dégustation minimale*' (for minimum standard taste) and '*ce produit peut être consommé après cette date*' (this product can be consumed after this date).[376]	Carrefour removed best before dates on products where these dates are not meaningful, such as vinegar, sauces, spices, and sweets, and extended use by dates on some meat- and dairy-based products.[384]
Norway	2017 2018	Q-Meieriene (Q-Dairy) changed their date label to '*best før (dato) men ikke dårlig etter'* ('best before (date) but not bad after').[385] Several Norwegian food producers including Q-Meieriene, TINE, and Norgesgruppen met and agreed on the new script for supplementary date labels to be 'best before (date), often good after'. This was applied to dairy products, eggs, orange juice, flour, and bread.[385]	The Norwegian Food and Hygiene Authority, Mattilsynet, was alarmed by the new label with concerns around misleading, ambiguous information. Matvett, a food industry organisation, was tasked with reaching a consensus on supplementary date labelling.[385] Q-Meieriene decided to the keep 'not bad after' phrasing, against the industry consensus.[385] A market research survey showed 77% of the respondents agreed that the new script explains the meaning of the date label better and 64% admitted they felt safer to use out-of-date products due to the supplementary date label. However, 67% of the same respondents answered that they did not need the addition as they already understood the original

Geography	Year	Action(s)	Evidence/outcome(s)
			best before well enough (though people who are informed on the topic may also be more likely to fill in the survey).[385]
Nordic Council (Denmark, Finland, Norway, and Sweden)	2017	The Council conducted a study on how regulations for date labelling are applied in Nordic countries. They also interviewed food industry actors on whether they use best before or use by date, and how they determine food durability.[386]	The study uncovered large variations in the durability estimates within product categories. Also, there were differences in the selection of the use by or best before date label within product categories.[386]
UK	2018	Major supermarkets including Aldi, Sainsbury, Waitrose, Tesco, and Marks & Spencer independently decided to remove best before dates on fresh produce and changed use by to best before labels on milk and yoghurt.[373] A note added on Sainsbury's product lines includes "no date helps reduce waste".[373]	The move by Tesco came after market research found 69% of customers would welcome a switch to products without best before dates and 53% said they would keep food longer if it did not carry a best before label.[387]
US	2016 2023	Laws vary state to state. The *Food Date Labelling Act 2016* was a bicameral bill proposed in both houses of Congress to provide federal oversight of date labelling, reducing the labels allowed and removing regulations that prohibit food banks' use of food past quality dates.[388] It was proposed again in 2021.[389] The proposal of the *Food Date Labelling Act 2023* aims to establish two standard date labels 'best if used by' for quality dates and 'use by' for discard or expiration dates and effectively end 'sell by'.[389]	The bill has faced opposition from an industry group funded by the Grocery Manufacturers' Association, Food Marketing Institute, and National Restaurant Association. They instead advocate for voluntary initiatives by industry.[390]

5. Retail and food service

Figure 25: A simplified depiction of the food supply chain highlighting the retail and food service stage.

In the food supply chain (see figure 25), 'retail and food service' (RFS) refers to consumer-facing businesses, like retail grocers, restaurants, foodservice providers, and various institutions, but can also include wholesalers and their distribution centres.[391] Typically, these businesses are divided into two groups:

- Retail: supermarkets, grocery stores, convenience stores, markets, and other outlets where consumers purchase food to prepare and eat at home. Here, we include wholesalers under retail, as these are often integrated into large supermarket operations.[392]
- Food service: establishments that prepare and serve food for immediate consumption, either on-site, takeaway, or through delivery. This includes restaurants, cafes, bakeries, fast food outlets, school and workplace cafeterias, hospitals, retirement homes, prisons, catering services, and other dining venues.[393] Businesses that sell food and drink to customers, such as bars, restaurants, and cafes, are often referred to as 'hospitality' and are included under food service.

5.1 Understanding food waste in retail and food service

In the food service sector, food waste is typically categorised into three types of waste: spoilage waste, preparation waste, and plate waste.[394] While these terms are not typically used to discuss retail food waste, some of these categories can have application to both RFS waste:

- Spoilage waste refers to food that becomes damaged or cannot be eaten because it's past its use by date and is potentially unsafe.[394] Similarly, in the retail sector, food may decline in quality for a variety of reasons (for example, poor handling or stock rotation) and become unmarketable, even if it remains safe to eat.
- Preparation waste refers to food that is discarded during the preparation of food for sale or consumption. For example, preparation of waste in hospitality may include vegetable peelings and trimmings or offcuts of meat (see figure 26).[394] This includes both edible waste (such as apple peel) as well as inedible waste (such as bones). While preparation waste is commonplace in the food service sector, it can also occur in some retail settings, for example, in in-house bakeries or delis.
- Plate waste refers to food that is served to customers but that is not eaten. Common examples of plate waste include servings of fries and garnishes.[394] For simplicity, we include 'serving waste'[395] – food that is wasted after being prepared and offered to the consumer but not taken, for example, table bread rolls or buffet waste – under the definition of plate waste. Plate waste is a category that generally occurs in the food service sector, although some grocery retailers may have in-house cafes that generate their own plate waste.

Figure 26: Quantifying data on food waste is a challenge for small food service providers, as evidenced by the preparation and plate waste generated at the Claris Sports and Social Club over the course of an evening.

5.1.1 Understanding supply chains

The retail supply chain in New Zealand

Much of the retail industry and supply chain in Aotearoa is dominated by two retail groups, a situation not dissimilar to Australia.* Foodstuffs NZ and Woolworths NZ held 80%-90% of the market share between them between 2015 and 2020.[392] IBISWorld data indicates these two operators make up "almost 75% of revenue for supermarkets, grocery stores, and convenience stores" in New Zealand.[396] Woolworths NZ is a subsidiary of the Australian Woolworths chain and operates Woolworths (currently rebranding from Countdown), Fresh Choice and Super Value brands.[396] Foodstuffs NZ consists of two cooperatives, Foodstuffs North Island and Foodstuffs South Island, owned by the 523 operators of the constituent stores operating under New World, PAK'nSAVE, Four Square, Raeward Fresh, and On the Spot brands.

The grocery supply chain consists of suppliers, wholesalers, and processors (see figure 27). Wholesalers act as go-betweens, buying produce from suppliers and selling it on to grocery retailers. However, in Aotearoa, Foodstuffs North Island, Foodstuffs South Island, and Woolworths NZ have their own integrated wholesale functions and distribution centres.[392,397] This means that, unlike in many other countries, major grocery retailers are not overly reliant on independent wholesalers for their products.[392] This 'vertical integration' means that these retailers wield greater influence over the food supply chain, and provides opportunities to reduce waste across the system.

> This 'vertical integration' means that these retailers wield greater influence over the supply chain, and provides opportunities to reduce waste across the system.

There are also independent wholesalers that encompass a broad range of businesses, including those specialising in fresh produce, meat, seafood, dairy products, and a variety of packaged foods and

* In Australia, the two largest supermarket chains—Coles and Woolworths—account for at least 70% of packaged grocery sales and 50% of fresh produce sales, figures that have remained largely unchanged over decades.

beverages.[205] In New Zealand, wholesalers cater to major grocery retailers, smaller grocery retailers, and the food service industry (see figure 27). For example, BidFood[398] supplies a range of food and kitchen consumables to the food service industry, while T&G[399] supplies a range of fresh produce to businesses in Aotearoa and around the globe. Smaller wholesalers might specialise in niche markets, such as organic or locally sourced foods, catering to specific consumer preferences.

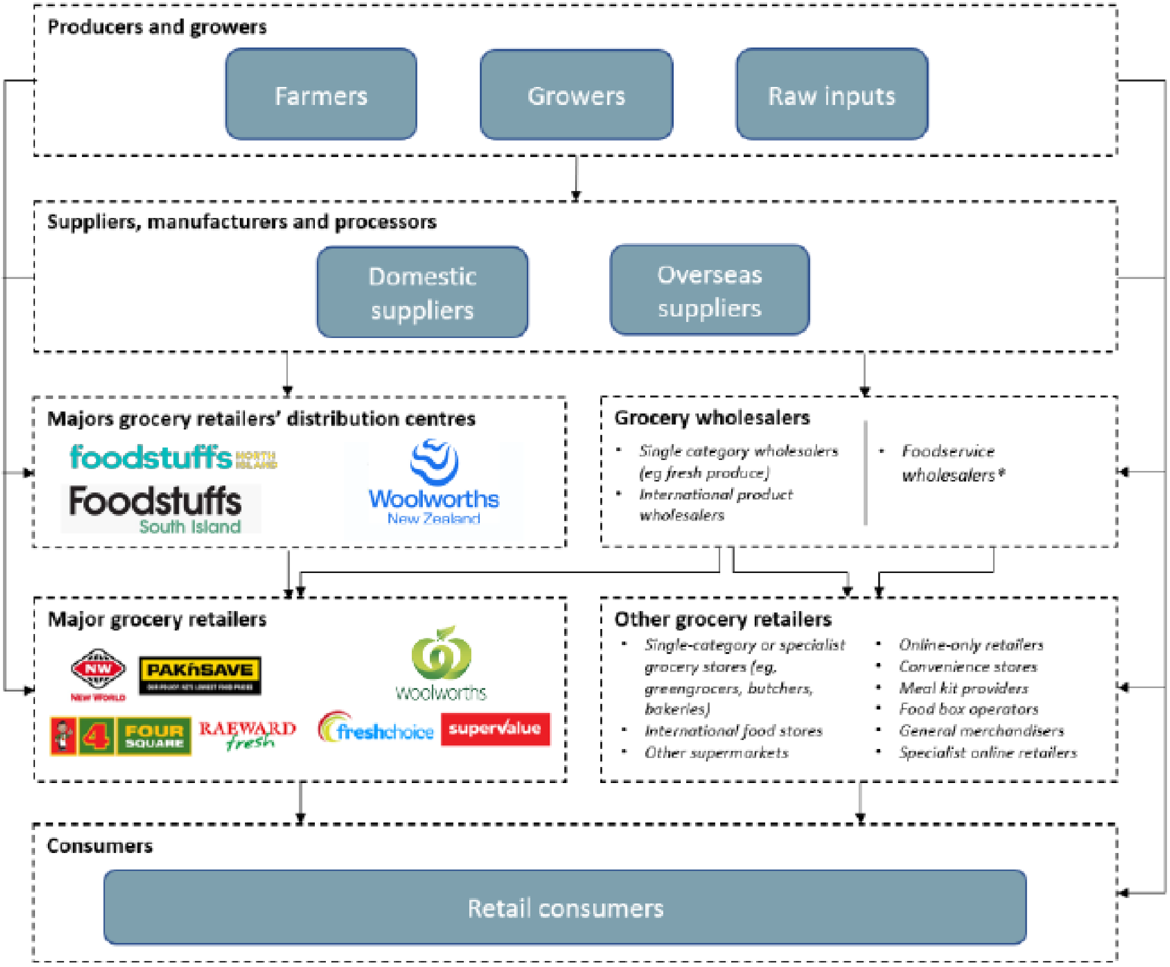

Figure 27: A high-level summary of the supply chain for the New Zealand grocery sector, adapted from a Commerce Commission report on the retail grocery sector.[392] The summary has been updated to reflect a change in branding for Woolworths NZ and both Foodstuffs North Island and South Island.[392] Note, the report included food service wholesalers in the retail supply chain as some of these wholesalers also supply grocery retailers, although this is not the focus of their business. For an overview of the food service supply chain, see figure 28.

The food service supply chain

We don't have as clear a picture of the food service supply chain in New Zealand as we do for grocery retailers, but we can approximate its general structure based on similar work from the UK (see figure 28). Waste within the food service sector focuses on food service outlets, including both hospitality and various institutions (such as hospitals, prisons, and universities). However, as will be discussed in section 5.2, interventions in the food service sector have the potential to reduce FLW up and down the supply chain.

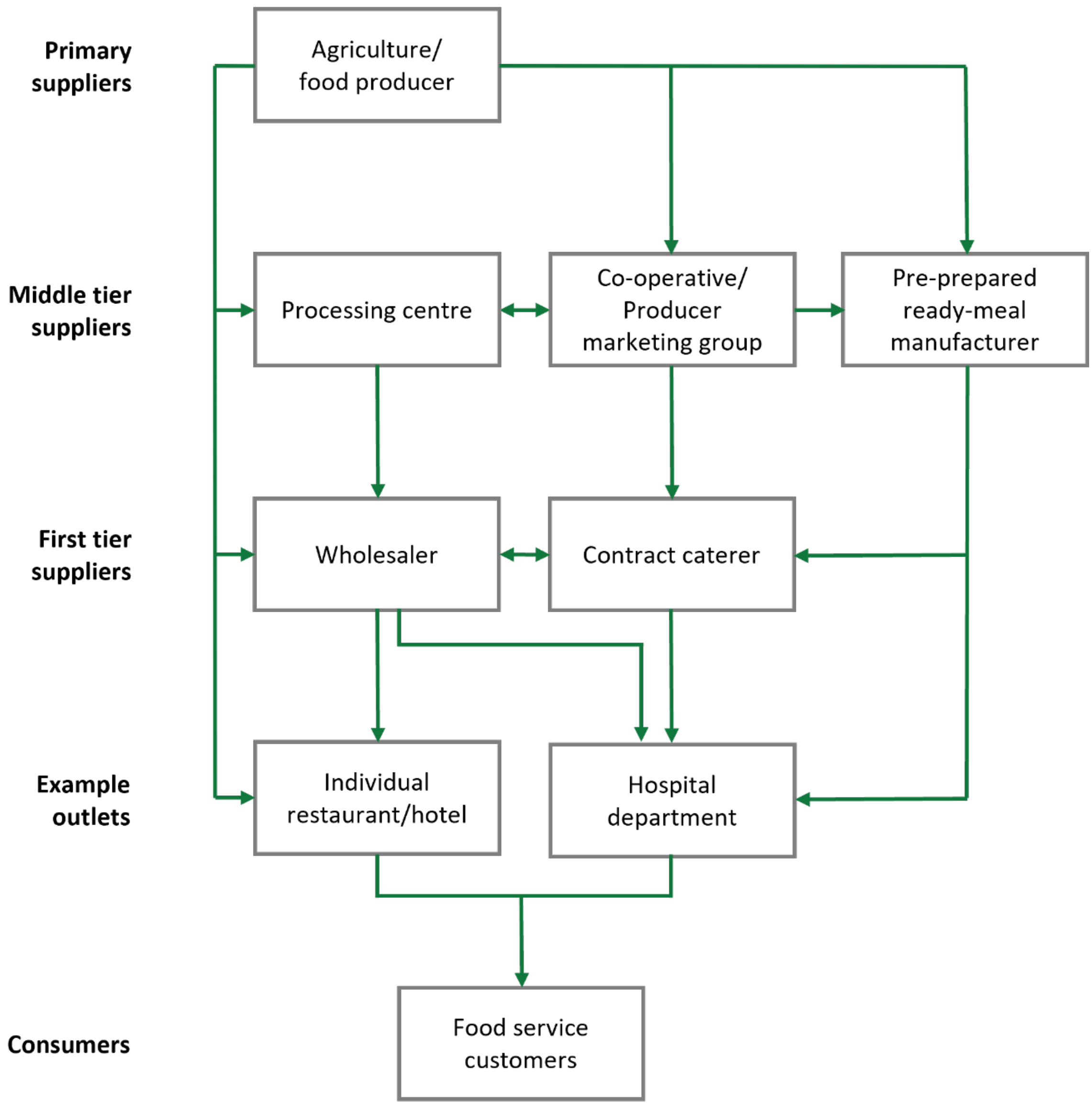

Figure 28: A generalised picture of the food service supply chain. Adapted from WRAP's 2013 report Overview of Waste in the UK Hospitality and Food Service Sector.[400]

5.1.2 What do we know about food waste in retail and food service?

How much waste is produced?

International evidence suggests food waste in RFS is produced in significant quantities. Estimates of food waste in different regions vary, in part due to differences in how waste is measured and/or allocated to different stages of the supply chain. The UN Environment Programme (UNEP) estimated that globally in 2022, 290 million tonnes of food were wasted in the food service sector, and 131 million tonnes in the retail sector.[401] In 2021, FIAL estimated that food wasted in wholesaling, retail, and food services accounted for 11% of all FLW along the Australian food supply chain, the majority of which was disposed of to landfills.[57] A 2022 estimate[402] for the US suggested that 9.5% of all FLW occurs within the distribution, wholesale, and retail stages of the US food supply chain, with a further 15% wasted in household and food service combined.

Extrapolating data from their global study released in 2024, UNEP estimates high-income countries like New Zealand waste 26 kilograms of food per person per year in the food service sector, and 13 kilograms per person per year in the retail sector.[401] This is consistent with a study undertaken in Aotearoa. A 2020 mixed-methods study estimated that food not sold or utilised at the retail level in Aotearoa amounted to approximately 13 kilograms per capita per year, with 3 kilograms per capita per year being sent to landfill.[67] For context, this is just less than half of the estimated 32 kilograms per capita per year wasted in New Zealand homes in 2018 (see section 6.1.1).[403] The retail study identified fresh vegetables (27%), bakery items (23%), meat and fish (19%), and fresh fruit (17%) as the major contributors to total discarded food. The research was informed by on-site food waste audits (16 stores), interviews, and analysis of existing data from three major retailers (Woolworths, New World, and PAK'nSAVE) across four major urban centres. The study extrapolated this data across all stores to estimate that 60,500 tonnes of unsold or unused product are produced annually, some 14,000 tonnes of which go to landfill. The study was the first – and remains the only – to quantify food waste at a retail level in New Zealand. A potential limitation is that the sample of stores was self-selected by participating retailers, which could introduce bias if retailers suggested stores with better waste management practices and result in an underestimation of retail food waste. Moreover, the sample was not representative of all supermarkets in Aotearoa (for example, there were no supermarkets in rural locations, or smaller businesses represented) so caution must be used in interpreting data scaled to a national estimate.

> …food not sold or utilised at the retail level in Aotearoa amounted to approximately 13 kilograms per capita per year, with 3 kilograms per capita per year being sent to landfill.

Analysis of New Zealand's hospitality sector by WasteMINZ in 2018 found that cafes and restaurants generate an estimated 24,400 tonnes of food waste each year, with an unknown proportion going to landfill.[404] Of this, 61% is considered avoidable waste, including preparation waste (60%), plate waste (33%), and spoilage (7%). The primary types of food wasted are vegetables (28%), bakery items (26%), meat (13%), and fruit (9%). Data informing the study were collected through bin audits of businesses (2017: five restaurants and four cafes in six different locations around the country; 2018: one restaurant and ten cafes in Auckland). Notably, the study audited twenty businesses for only a single day, limiting the precision of its findings. Additionally, the study did not cover food waste for other food service providers – such as pubs, bars, and hotels, or institutions like prisons, or retirement homes – about which little is known.[405]

Data from two New Zealand hospitals indicates that institutions also have work to do in preventing food waste: over a two-week period in 2014, an unnamed hospital served around 1750 meals per day and generated a total of 350 litres of food waste, while another unnamed hospital served 2,420 meals per day and produced 200 litres.[406] Additional research on plate waste in New Zealand hospitals indicates that approximately 400 grams of food waste is produced per plate, equating to 31% of served food going to waste.[407] Most food waste in hospitals is sent to landfill; food donation from hospitals are limited by hygiene and food safety constraints,[408] and only 10% of hospitals compost their organic waste.[407] Overproduction, inaccurate forecasting, and portion sizing were considered key drivers of this waste.[406] To help understand the scale of food waste in other parts of the food service industry, MfE is funding research in the food service sector, with ongoing projects evaluating food waste in retirement homes and hospitality.

While we have some data on food waste in RFS in Aotearoa, we do not have a good understanding of its share of FLW along our supply chain.* If these sectors follow patterns seen in Australia[57] or the UK,[400,409,410] it's likely to be a small proportion of our total FLW, albeit still in significant amounts. However, this is only reflective of waste that occurs within the sector. Importantly, practices and standards set within the RFS sector can have a significant impact on FLW patterns up and down the food supply chain (see section 5.2).

> …practices and standards set within the RFS sector can have a significant impact on FLW patterns up and down the food supply chain.

What are the drivers of food waste in the retail sector?

According to ReFED, food waste in the retail sector can arise from a combination of consumer-driven and operational factors.[391] For example, retailers can build in wasteful practices like overstocking shelves (see box 6). On the operational side, silos within retail supply chains can inadvertently exacerbate food waste, as different parts of a business fail to manage complex inventories and ensure older products are sold before newer ones (i.e. poor stock rotation). Consumer and operational factors can also interact, for example, customer demands for variety and consistency in food products can put strain on retailers' inventory management and food purchasing. Moreover, cosmetic standards on produce, determined by retailers and reinforced by consumer expectations for freshness, can lead to perfectly good food being thrown out simply because it's nearing its best before date or doesn't look appealing.[411] ReFED estimates that concerns around date labels account for more than 50% of food waste at the retail stage of the US food supply chain.[389] (See section 4.2.3 for an overview of date labelling practices and potential solutions.)

Box 6: Shelf overstocking – a retailer's dilemma

Retailers face a trade-off in how they stock their shelves, with 'overstocking' a key problem. Simply put, shelf overstocking is when retailers stock more products on store shelves than can be sold before products reach their expiration or become less desirable to consumers (see figure 29). Driven by competition, many retailers prioritise product availability and diversity, thus overstocking shelves to drive sales.[412] However, while increasing a store's attractiveness to consumers, overstocking brings with it negative effects. Economically, overstocking can cause a direct financial loss due to unsold inventory† as well as additional costs for handling, passing on, and/or disposing of food waste. Environmentally, overstocking drives the waste of food itself, and in turn the resources used to produce, transport, and store overstock food. As highlighted in table 15, there are several interventions that can help reduce excess food in supermarkets, although reactive initiatives like price promotions are likely insufficient by themselves.[412] Instead, more nuanced and demand-driven approaches such as incorporating better demand forecasting, tailoring product ranges to better match sales data, and varying stock availability among different products, are required to design out waste associated with a one-size-fits-all approach to stocking.[412]

* UoO (commissioned by MfE) are conducting a national baseline study of FLW; results are forthcoming.

† Depending on specific terms of trade agreements, sometimes this economic impact can fall on the producer or manufacturer of foods rather than the retailer, as is commonly observed in the bread industry (see section 2.1.2).

Figure 29: While overstocking can make shelves look attractive, doing so for highly perishable items (for example, bread and other bakery items, minced meat, fish, takeaway snacks, and some fruits and vegetables) can exacerbate the dilemma of appealing to customers while trying to avoid food waste.

A recent systematic review of food waste causes and reduction practices in the (global) retail sector suggests that issues with procedures, equipment, and materials used in the industry, inefficient labour practices and problems with waste measurement, as well as wider challenges in the retail environment entrench food waste in the sector.[413] The drivers of food waste within these groupings are presented in table 9 below.

Table 9: A diverse range of factors can generate food waste in the retail sector, presented here as identified and grouped by De Moraes et al.[413] Groups are ordered as listed in the study, giving weight to the frequency with which these groups are discussed in academic literature. It is worth noting that these drivers are reported from a generalised context from a broad review of academic literature on retail food waste; there is no equivalent research specific to New Zealand. Abbreviations: IT = information technology, NGOs = non-governmental organisations.

Group	**Food waste driver**
Environment.	• Overly restrictive laws, including general commercial standards, as well as hygiene and food safety standards. • Uncertainties in supply chains caused by climate change; for retailers this creates issues with demand forecasting and food availability. • Problems with seasonal foods that influence demand and supply, as well as changing specifications in relation to seasonal changes. • People's eating habits can drive food waste. For example, unpredictable changes in buying preferences can result in unforeseen changes to demand. Additionally, the size of foods available for purchase for small or single-person households can influence waste in the home.

Group	Food waste driver
	• Excessive stakeholder pressure on retail shares by government, legislators, NGOs, and shareholders, which can increase or reduce food waste.
Equipment.	• Cold chain gaps, i.e. the lack of structure and equipment needed to maintain (lower) temperatures for perishable foods over a long period of time. This is made more complex by different food types requiring different temperatures. • Poorly maintained, outdated, or poor in technical condition transport equipment that causes damage to food as it moves within retail supply chains, for example, from wholesalers to retailers. • Storage that is not strategically located, lacks capacity, and/or does not have adequate cooling and ventilation. • Ineffective and problematic display of products on shelves. For example, stacking large piles of certain fruits can result in physical damage to food.
Human factors.	• Incorrect handling, including failures to package food and over-handling fruit and vegetables. • Lack of training and/or knowledge on food waste mitigation practices. • Lack of commitment to food waste practices.
Materials.	• Inadequate packaging, including during transport and storage (see section 4.1.2) as well as confusing and incorrect labelling of expiry dates (see section 4.2.3). • Short shelf life, in particular for fruit and vegetables.
Measurement.	• Inadequate demand forecasting systems, i.e. the inability to accurately predict demand and supply, in particular for foods with a short shelf life. • Overstocking inventory to cover uncertainties. • Lack of (standardised) waste measurement. • Sudden changes in orders, in particular for promotions that drive unpredictable demand and waste.
Procedures.	• Stringent specifications of appearance and shape of food, particularly fruit and vegetables (see section 2.1.2). • Poor management and rotation of inventory. • Lack of coordination and collaboration within retail supply chains. • Lack of information sharing, including not sharing data openly and not adopting advanced demand forecasting techniques. • Inappropriate procedures to manage food waste, for example, unclear approach to food donation. • Lack of integrated IT systems, resulting in failure to share and quickly communicate information between supply chain links.

What are the drivers of food waste in the food service sector?

Like the retail sector, food waste in the food service sector is a complex issue influenced by a range of factors, spanning societal norms, business styles, procurement strategies, customer expectations, and more.[414] Key drivers include operational practices within the food service establishments, such as overproduction of food, poor storage and handling techniques, and large portion sizes that often result in leftovers.[400] ReFED estimates that some 70% of food waste in the US food service sector is plate waste from consumers who don't eat all that they're served, or take from a buffet.[415] This may be lower in Aotearoa, with plate waste accounting for 33% of food waste in restaurants and cafes, as per data from a single study.[404] Consumer behaviour and expectations also play a significant role, where customers' specific preferences and demand for variety and aesthetics in food presentation can lead to more waste.[414] Furthermore, outlets like restaurants or cafes in the sector face the challenge of balancing menu complexity, portion sizes, and food waste.[400] A wide enough range of menu items is needed to satisfy and attract customers, but can increase the likelihood of waste due to the need for more diverse ingredients, especially if outlets can't accurately predict demand for different menu items.[400]

Another significant factor is a lack of planning and inventory management, leading to over-ordering or overstocking, which can result in food spoilage.[416] Training and awareness of staff in food service establishments are crucial as well, as inadequate knowledge and skills in food waste reduction can exacerbate the problem. Regulatory constraints and health concerns sometimes lead to more food being discarded as businesses err on the side of caution.[414] Lastly, a lack of food waste tracking and measurement makes it difficult for businesses to identify and effectively address specific areas where waste is occurring.[410]

5.1.3 What are the gaps in our knowledge?

There's a lot we don't know about food waste and prevention efforts in our RFS sectors. This means we have knowledge gaps that span a range of issues, including but not limited to:

- Much of our understanding of food waste volumes, types, and potential interventions in the RFS sector comes from examples and research overseas. Thus, in many instances we lack context specific data and must rely on inference to understand the potential effect of interventions on food waste reduction efforts in the sector.
- Generally, research in the sector has been more focused on considering the causes of food waste than on reduction practices.[413]
- Much of our local understanding of food waste in the New Zealand RFS sector comes from a study of big retailers,[67] a hospitality-focused study on twenty restaurants and cafes,[404] and some research into hospital food waste.[406,407] There is little New Zealand specific data about food waste and/or reduction practices in small retailers, independent wholesalers, and a wide variety of food service providers (for example, bakeries, meal delivery services, meal kit companies, and various public institutions.
- Other than for some of our larger retailers,[67] we have little idea of where food waste in the sector is being diverted to.
- We do not know how much the RFS sectors waste food in relation to other parts of the supply chain, nor do we know the extent to which their practices (for example, cosmetic specifications and ordering contracts) cause FLW upstream in the supply chain.

5.2 How can we prevent food waste in retail and food service?

Despite challenges in assessing their efficacy, we have taken a deep dive into the interventions touted as useful for FLW prevention in the RFS sectors (see section 5.2.1 and annex 3). Because RFS actors are uniquely positioned in the supply chain, bridging producers and consumers, their ability to influence and reduce FLW extends beyond their own sector. This is particularly true of retailers and wholesalers, whose practices and policies dictate the flow of significant amounts of food along the supply chain,[392] and can affect how food is produced, processed, distributed, and consumed (see section 1.2). Later in this section, we discuss interventions for the RFS sectors that may have positive effects on FLW elsewhere in the supply chain.

Using our case study of the tomato supply chain (see case study 1), we can explore the potential for retailers to influence FLW upstream in production (see section 3) and processing and manufacturing (see section 4), in their own sector, and downstream. Upstream, retailers can mitigate waste by selecting suppliers with accredited sustainable farming practices and creating transparent supply contracts where tomato waste is a mutual consideration, employing more accurate demand forecasting to avoid over-ordering, and accepting cosmetically imperfect but edible tomatoes. In-store, effective strategies to reduce tomato spoilage include implementing a 'first in, first out' (FIFO), or alternatively 'first expired, first out' (FEFO)[417] (see box 7) system to ensure older tomatoes are sold first, handling tomatoes with care to avoid bruising and soft spots, maintaining optimal storage conditions, and promoting or discounting tomatoes that are near the end of their shelf life. For downstream waste mitigation, retailers can provide in-store education to consumers on typical shelf life, proper storage, and tips for using tomatoes in the household.

Box 7: First in or first expired? Comparing FIFO and FEFO approaches to inventory management

FIFO and FEFO are two key inventory management strategies that differ primarily in their application and the nature of the inventory they manage.[418,419] FIFO is typically used where products do not have an expiration date and is aimed at moving the oldest continuous stock first, thus ensuring that the inventory remains fresh and relevant. This method is particularly useful for non-perishable goods such as canned goods or household items.[419] It also helps in maintaining a lower inventory cost and less obsolescence since products that come in first are sold first.

FEFO, on the other hand, prioritises the dispatch of products based on their expiration dates and is crucial for industries like food and pharmaceuticals, where selling products past their expiration can lead to health risks and legal issues. By prioritising products based on expiration rather than purchase date, FEFO helps grocery retailers and food service providers manage products for both consumer safety and regulatory compliance.[418] In addition, FEFO inventory management has significant potential to reduce wasted food, and concurrently boost sales and enhances customer trust in fresh food options.[417] However, caution is needed not to create perverse incentives to label fresh produce with a short expiry date.

In short, both methods aim to optimise inventory turnover and reduce costs associated with excess, outdated, or expired stock. However, the choice between FIFO and FEFO largely depends on the specific needs of the business, including the type of products handled and their respective shelf lives.

5.2.1 There are interventions that can prevent food waste within the retail and food service sectors

Interventions that prevent and reduce food waste within the RFS sectors target spoilage, preparation waste, and plate waste – the most common types of waste in the sector. Because the sector is so varied, both in the businesses that it comprises and the opportunities for waste, interventions to prevent food waste are wide-ranging (see annex 3).

A detailed list of potential interventions to prevent food waste and the evidence for each is presented in annex 3. Note that much of the evidence for interventions in RFS provided in this table is international research and not specific to the Aotearoa context. As explained in section 5.1.2, New Zealand-specific research in this part of the supply chain is scarce. This is something we should aim to improve but should not let this delay action based on international evidence, ensuring robust evaluation of interventions.

According to ReFED data from the US (see figure 30), one of the most effective and financially beneficial approaches for retailers to reduce food waste is to prioritise sales of products nearing expiry.[417] This includes using markdown alert applications or distress sale platforms and dynamic pricing of goods in accordance with their remaining shelf life. These strategies are also available to food service providers, with apps like Footprint[420] in Aotearoa and ResQ Club[421] in Europe highlighting perfectly good food available at reduced prices from various local eateries. We discuss these interventions in more detail in annex 3, with available evidence suggesting these solutions can be highly effective in reducing food waste.

…one of the most effective and financially beneficial approaches for retailers to reduce food waste is to prioritise sales of products nearing expiry.

In addition to prioritising sales, a key operational step to minimising food waste in RFS environments is efficient inventory management. In a perfect world, the full inventory of food bought from suppliers by RFS would be sold on to consumers, in optimal condition. While perfection may be a stretch, a range of solutions for inventory management can help reduce food waste as food moves from producers to consumers. Advanced demand forecasting (sometimes called enhanced demand planning), which typically employs ML to predict consumer demand more accurately, has potential to significantly reduce spoilage waste in RFS sectors.[422] Pairing this approach with inventory management strategies like FEFO,[423] as well as optimised storage and transport (see section 2.1.1) can provide further improvements to food waste reduction efforts and provide significant financial benefits to RFS sectors. For example, in the US retail sector, ReFED estimates that retailers could divert around two million tonnes of food from waste annually, with a net financial gain of some US$5.5 billion if they enhanced product distribution methods and refined inventory management systems (see figure 30).[424] As further discussed in annex 3, available evidence for the effectiveness for such interventions is largely positive, although data is patchy.

…ReFED estimates that retailers could divert around two million tonnes of food from waste annually, with a net financial gain of some US$5.5 billion if they enhanced product distribution methods and refined inventory management systems.

Beyond managing their inventory effectively, food service providers can implement interventions that target preparation and plate waste. Providing diners with doggy bags, changing portion sizes, adjusting plate sizes, and tweaking the dining set up in buffet style services can all reduce plate waste, while improving menu planning and tailoring staff training can reduce preparation waste (see annex 3).

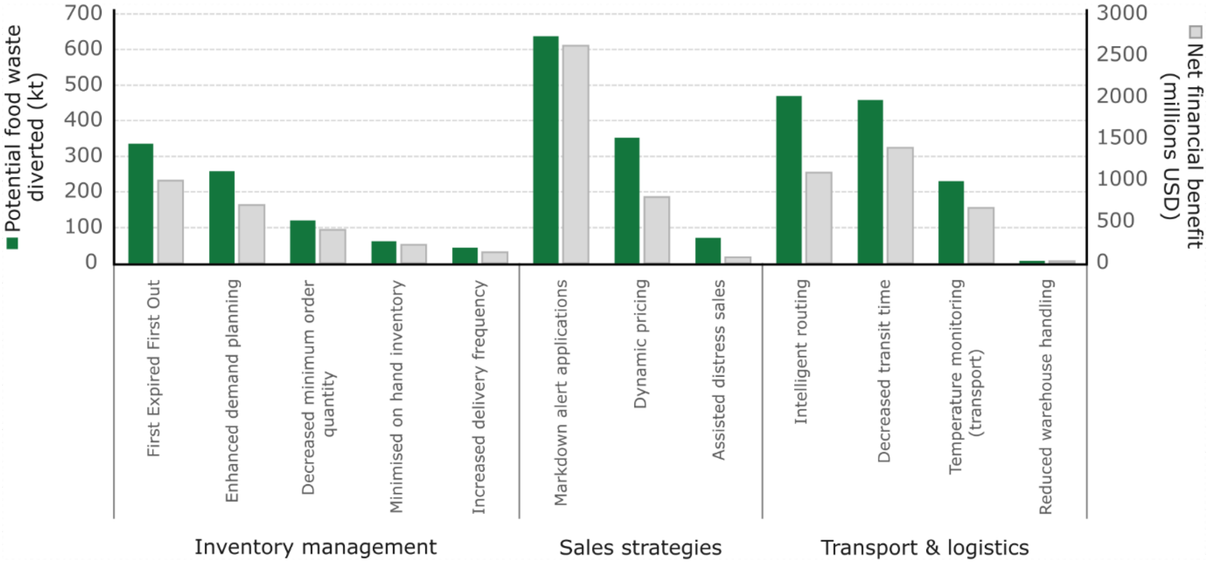

Figure 30: The potential for annual food waste diversion (kilotonnes – green bars, left axis) and annual net financial benefits (US dollars, in millions – grey bars, right axis) of food waste interventions in the US retail sector, as estimated by ReFED.[424] Data source: the ReFED Solutions Database.[424] Data was sorted into three general categories of intervention (inventory management, sales strategies, and transport and logistics). Abbreviations: kt = kilotonnes, USD = US dollars.

The potential of a given intervention to prevent food waste cannot be narrowly measured in terms of 'effectiveness' – whether it works – but also in terms of the real world conditions, which will shape an intervention's implementation and impact. In 2018, ReFED considered five criteria in their assessment of interventions for retail (see figure 31) and food service (see figure 32) in the US: profit potential (expected net annual profit, not including upfront investment costs); feasibility (implementation effort and initial capital requirement); industry prevalence (estimated percentage of retail providers that have implemented a solution); diversion potential (portion of all food waste – by weight – that could be diverted from landfill through implementation of the solution); and economic value (the annual aggregate financial benefit of a solution to society minus all investment and costs). As figure 31 and figure 32 show, no interventions score highly on all criteria. For example, in 2018, enhanced demand planning had significant potential to improve profits and divert food from landfill, but was difficult to implement and had a low industry prevalence in the US (see annex 3). Conversely, changes to cosmetic specifications were deemed highly feasible, but had relatively low potential to improve retailer and food service profits, with a moderate predicted impact on food waste reduction. Importantly, ReFED's assessment is context and time specific. For example, enhanced demand forecasting was indicated to have low feasibility based on ReFED's 2018 data, but several retailers have started using it successfully in 2024.[425] ReFED's Insights Engine[423] provides a range of up-to-date impact metrics for solutions like enhanced demand planning, although it does seek to not quantify their feasibility.

Importantly, retailers and food service providers alike may struggle to prioritise interventions for food waste reduction because they lack quantifiable information about where and why food waste is occurring. As highlighted in section 2.2.2, improvements and innovation in supply chain digitalisation and data collection can help identify waste hotspots and lead to better insights around the flow of food, and waste, within supply chains. For example, within food service, identifying and tracking the types and volumes of food that are disposed of during preparation can inform and optimise operations, increase profits, and help form a business case for investment in other food waste solutions.[415] As is true across the supply chain, without robust measures of food waste, it's difficult to select or design effective interventions for food waste reduction, set credible goals, or monitor progress.[426] By enabling tailored interventions, measuring waste has enormous potential to reduce food waste. For example, in the US food service industry, ReFED estimates that technology-enabled tracking of food waste could help divert some one million tonnes of food waste from landfill, with a net financial benefit of almost US$4 billion.[415] Additionally, in the retail sector, tracking waste is key to evaluating key performance indicators that target food waste reduction.[427]

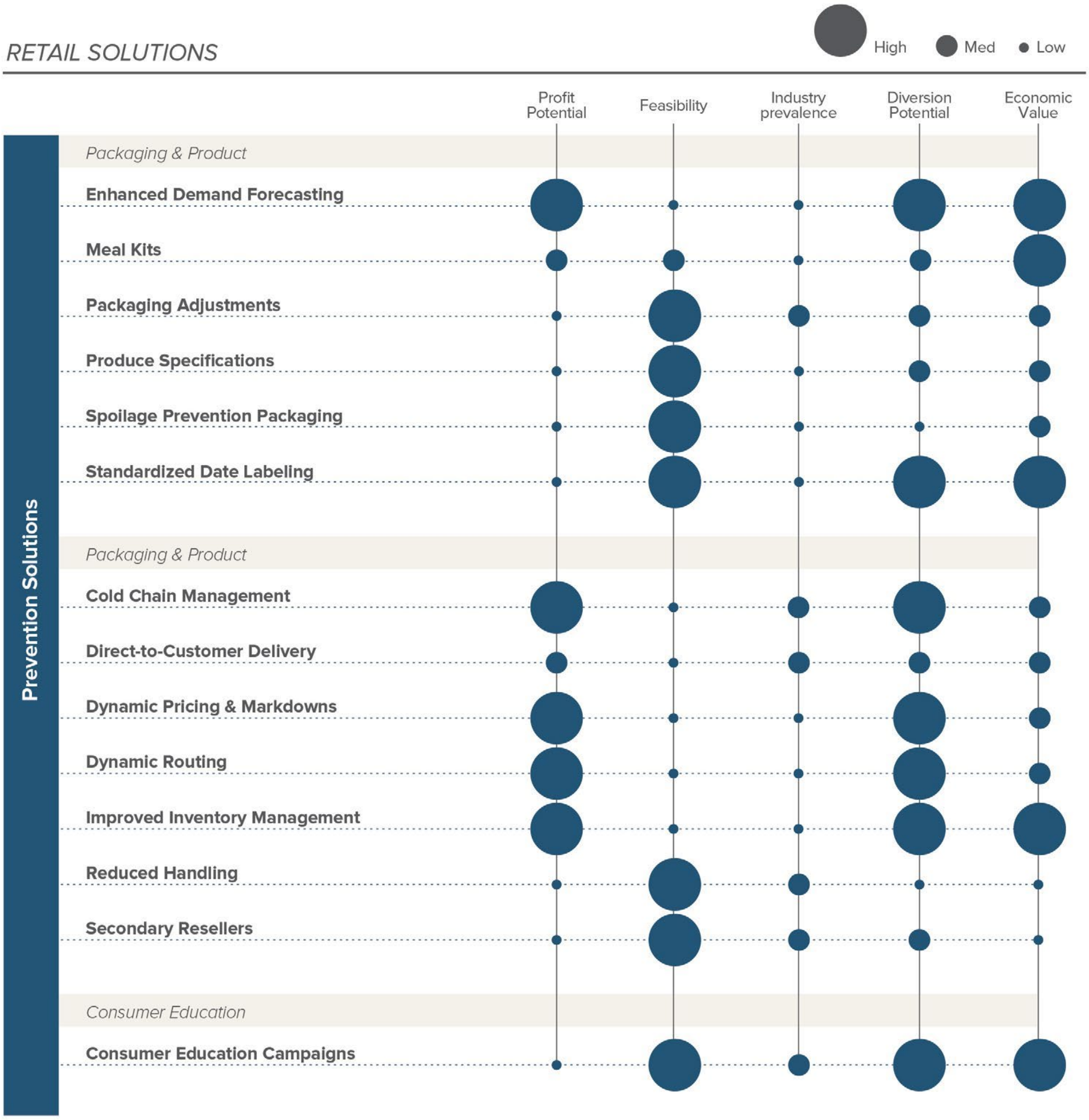

Figure 31: A 2018 ReFED assessment of solutions to food waste in the US retail sector, according to five criteria: profit potential, feasibility, industry prevalence, diversion potential, and economic value.[391] Note, in this report, we introduce concepts of produce specifications in section 2.1.2, packaging solutions in section 4.2.2, and standardised date labelling in section 4.2.3. Image credit: ReFED.

In many instances, interventions to reduce food waste in retail stores and food service providers are complementary. For example, reducing minimum order quantities[428] can be strategically coupled with increased delivery frequencies, especially where dwell times are reduced.[429] Similarly, efforts to pair improved demand forecasting with dynamic pricing are sensible; the former can help stores get just the right amount of food into stores, while the latter is a failsafe for when forecasting gets it wrong and too much food is on hand.[391] The same is true for interventions to shape consumer expectations; making people more aware of food waste, giving them tips on how to avoid it, and simultaneously changing the way food is presented in stores to influence buying habits can make a difference.[430]

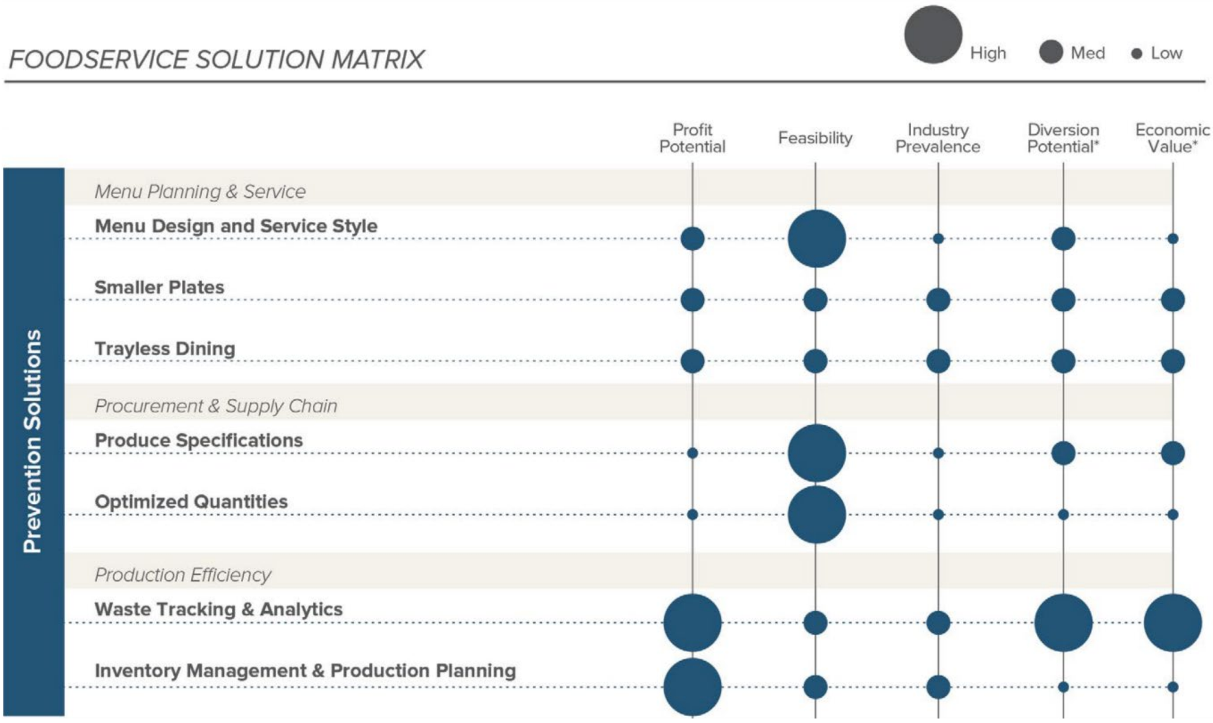

Figure 32: A 2018 ReFED assessment of solutions to food waste in the American food service sector, according to five criteria: profit potential, feasibility, industry prevalence, diversion potential, and economic value.[416] Note, in this report we introduce concepts of produce specifications in section 2.1.2. Image credit: ReFED.

5.2.2 Preventing FLW upstream: the role of retailers and food service

The RFS service sector can inadvertently cause FLW earlier in the supply chain through several mechanisms. These practices, often rooted in operational efficiencies and market expectations, can have a cascading effect on suppliers, leading to inefficiencies and excess waste well before products reach the consumer. While a host of different drivers can cause food waste within RFS sectors (see section 5.1), here we discuss two broad areas for intervention – cosmetic specifications and ordering practices – and their effects on FLW upstream in the food supply chain.

Cosmetic specifications

One of the primary ways retailers and food service providers contribute to upstream FLW is through stringent cosmetic specifications for produce (as introduced in section 2.1.2).

Several studies indicate that cosmetic specifications can contribute substantially to FLW in retail and production alike. For example, a 2018 study of EU retailers and producers estimated that producers discarded roughly half of their out-of-spec produce, while waste within retailers varied substantially.[76] German retailers assessed that 2% to 40% of delivered fruits did not fulfil their cosmetic specifications, while in the Netherlands, retailers assessed their own wastage to be extremely low (1%).[76] However, Dutch producers suggested their on farm losses due to cosmetic specifications ranged from 2% (greenhouse production of tomatoes) to 25% (open field production of lettuce and cabbage).[76] Another 2018 study of food loss in fresh fruit and vegetable production in the UK and Europe estimated that over a third of total farm production is lost for 'aesthetic reasons', with on farm cosmetic rejections of up to 4,500 kilo tonnes per year in the UK and 51,500 kilo tonnes per year in the European Economic Area[77] (see section 3.1.3). While these studies highlight that cosmetic specifications may cause FLW, they did not test the effectiveness of broadening cosmetic specifications as a tool to reduce FLW. In 2009, the EU removed cosmetic specifications for 26 of 36 product types, a decision which had reportedly little effect on FLW because retailers retained their own cosmetic specifications[431] to satisfy assumed consumer expectations. In a New Zealand context, where the Government regulates standards around food safety and packaging but not cosmetic appearance,[355] changes to cosmetic specifications will likely need to be led by retailers and require buy in from all actors along the supply chain.[77]

Retailers are not the sole creators of specifications (see box 2), but their unique position in the supply chain means they have considerable potential to reduce FLW driven by cosmetic specifications. Retailers can help increase consumer acceptance criteria for produce, promoting and marketing ‘imperfect’[*,432] fruits and vegetables to consumers (see case study 11). This can help prevent food loss on farms, as supermarkets buy a wider range of products. Taking on a greater variety of produce has implications for sales strategies, with novel approaches needed to ensure that FLW isn’t simply passed from farm to retailer. Initiatives to market imperfect produce, such as Woolworths NZ’s ‘Odd Bunch’,[†] coupled with in-store consumer education and competitive pricing could be helpful tools in changing customer purchasing patterns,[433-436] and in turn reduce FLW along the supply chain. A range of food service providers also use and market imperfect produce (see sections 2.2.4 and 3.1.3). These include retail produce box companies like Perfectly Imperfect,[28] Wonky Box,[29] and Farmers Pick,[437] as well as customers in the food service sector,[438] and others getting in on the act.[439] In many instances, imperfect foods are well-suited to the food service sector because they are flavourful yet cost-effective and are particularly useful for dishes where the appearance of ingredients is less important, such as soups, salads, or sauces.[440] Relaxing specifications is not without its complications for retailers, with considerations around brand image, operational adjustments, and food safety misconceptions. However, emerging evidence suggests that retailers who do broaden their cosmetic specifications can be successful in selling imperfect produce, especially if retailers can overcome consumer concerns of quality and appropriate pricing.[441,442]

Retailers are not the sole creators of specifications, but their unique position in the supply chain means they have considerable potential to reduce FLW driven by cosmetic specifications.

Supply chain coordination: Leveraging analytics and collaborative relationships

As discussed in section 2.1.1, ineffective coordination across the supply chain is a major factor that stimulates food overproduction and can see food lost before it reaches market or result in spoilage due to misaligned delivery and usage timelines. A range of practices drive this waste,[443] including analytical factors like inaccurate demand forecasting, as well as ordering practices that build in waste, including inflexible orders, short lead times, last-minute cancellations, a lack of commitment

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[*] Here the term imperfect is used to describe foods that deviate in appearance from consumer expectations, as influenced by cosmetic specifications. In academic literature, these foods are often called 'suboptimal'; an umbrella term, which describes food that consumers perceive of lesser value than other items of the same kind. Foods can be considered suboptimal for a variety of reasons: they’re nearing their indicated expiration or best before date, they deviate in appearance (i.e. imperfect foods), or their packaging is damaged.

[†] Critics of this scheme note that that this line of produce is only available as a bulk buy, a marketing approach that can promote food waste in the home by encouraging over purchasing.

to contracts, and terms of trade like take-back agreements[72] (see section 2.1). The power imbalance between smaller suppliers and the large retail chains (and their associated wholesale companies) is a significant contributor to poor ordering practices.[392]

Poor demand forecasting is largely a technical issue, and one that can be improved by leveraging better data analytics to predict demand and in turn enable more accurate ordering. As highlighted in annex 3, employing analytics to improve demand forecasting has considerable potential to alleviate food waste in the retail sector, although it's not straightforward to implement and is not widely practiced (see figure 32). Additionally, where demand forecasting tools are used, preventing FLW would be enhanced by sharing the information gained from such tools with suppliers. While issues around order flexibility, timing, and contracts could be aided by technical improvements like supply chain digitalisation (see section 2.2), the crux of these issues come down to the nature of relationships between suppliers and retailers and/or food service providers.[444] Given that a lack of coordination and collaboration between suppliers and retailers is one of the most cited causes of food waste,[413] this is clearly not a straightforward fix. Establishing stronger, more collaborative relationships with suppliers can encourage more realistic lead times and contract terms,[443] reducing the pressure to overproduce (see section 2.1 and section 3.1). Food retailers can also be more systematic in sharing forecast data for specific food items with farmers to optimise their production plans (see section 2.2.2).[445]

...where demand forecasting tools are used, preventing FLW would be enhanced by sharing the information gained from such tools with suppliers.

In addition, some authors have argued that retailers should take more accountability for FLW caused by their ordering practices through, for example, take-back agreements and shared financial risk of food losses with producers.[446] There are examples of these arrangements in practice: a UK retailer guaranteed 98% of their orders in banana production, building tolerance into contracts that account for production delays and overproduction.[447] Similarly, Sainsbury's in the UK has established a close working relationships with sheep and dairy farmers, resulting in practices like 'cost of production' pricing models that help avoid on farm losses of livestock, reflect the real costs of farming operations, and builds in profit.[445] In Aotearoa, the recently introduced Grocery Supply Code (see box 8) has potential to bring more certainty and transparency to supplier-retailer relationships. It remains to be seen if the code has a positive effect on FLW reduction efforts.

Case study 11: How Tesco collaborates with suppliers to reduce food loss and waste

Retailers can collaborate with farmers to develop clearer and more flexible procurement policies to reduce pre-retail FLW, ensuring a market for a wider array of produce, providing growers with more certainty over orders, and prioritising more seasonal and local produce.[448] UK retailer Tesco has openly made food waste reduction part of its wider business strategy, becoming the first UK retailer to report their food waste statistics publicly.[449] Tesco has implemented several initiatives with suppliers to reduce pre-retail waste. For example, Tesco's 'Perfectly Imperfect' line of fruit and vegetables (see figure 33),[449] launched in 2016, has provided an avenue to market for a greater cosmetic variety of produce. According to Tesco, this strategy has seen a significant reduction in food waste, with the 2024 estimate suggesting that 68 million packs of fruit and vegetables were saved from going to waste.[449] Between 2016 and 2021, the company claims that 44,000 tonnes of produce were sold through the initiative, with potatoes (12,600 tonnes), carrots (10,500 tonnes), apples (8,700 tonnes), and strawberries (8,500 tonnes) being the most popular.[450] In addition to purchasing and selling imperfect produce, Tesco has also worked with suppliers to manage and purchase bumper crops – a situation that arises when farmers produce more than they were expecting. For example, a UK heatwave in 2022 saw an unexpected surge in local strawberry and cherry production, with Tesco purchasing the excess to sell kilo boxes of summer fruits at discounted prices.[449]

Figure 33: Tesco's Perfectly Imperfect line of fresh produce comprises a variety of fruits and vegetables, such as strawberries (left) and carrots (right). Image credit: Tesco.

In addition to flexible purchasing, Tesco launched an online marketplace in 2022, called 'Tesco Exchange',[451] that matches suppliers who have too much product with other Tesco suppliers that need product. The idea behind the platform is to enable some 3,500 Tesco suppliers to cut production costs and reduce waste by selling or donating stock that may previously have gone to waste. At time of writing, data pertaining to the amount or types of stock sold on the platform have not been published in recent Tesco reports.[449]

Box 8: The Grocery Supply Code

A notable recent development for the retail supply chain was the introduction of the Grocery Supply Code (the Code) in 2023; a piece of legislation designed to help regulate relationships between suppliers and retailers.[452] While the Code is not designed around FLW specifically, its promotion of fair, certain, and transparent agreements between suppliers and retailers could influence, and hopefully benefit, FLW prevention efforts. For example, the need for retailers to provide 'clear and reasonable' specifications for fresh produce, documented reasons for rejecting produce, and written agreements over quantity and quality requirements could provide suppliers with more certainty in their trade dealings and production needs. Similarly, the Code's requirement for retailers to provide suppliers with adequate notice for delisting products or creating promotions, could help suppliers with their forecasting efforts and help cut back on FLW. However, given the Code only came into effect in late 2023, we don't yet know it's impact on FLW prevention within the retail supply chain.

5.2.3 Preventing food waste downstream: the role of retail and food service

Food waste in households: Opportunities for retailers

Retailers, given their direct and frequent interactions with consumers, can influence and prevent food waste in households through a combination of strategies aimed at educating consumers and modifying purchasing patterns.

A frequently discussed approach for retailers involves in-store education around making the most of food, with in-store signage, online resources, pamphlets, store magazines, on-pack stickers, and organising in-store events all commonly used approaches.[445] Evidence from the UK suggests that communication from retailers to their customers around food waste can have a significant effect on reducing food waste of consumers,[453] with consumers looking to retailers for guidance and to set an example.[445] By providing clear, accessible information on food preservation, storage, and waste reduction, retailers can empower customers to make more informed decisions that align with FLW goals. In section 4.2.3, we discuss some of the labelling options that can make this type of information accessible. It's also important to consider different types of customers because people have various reasons for wanting to reduce food waste. Understanding these differences can help come up with targeted strategies that are more likely to work.[433]

> By providing clear, accessible information on food preservation, storage, and waste reduction, retailers can empower customers to make more informed decisions that align with FLW goals.

As discussed in section 4.2, there are many ways that improvements to packaging, and packaging information can prevent food waste. Retailers can make impactful changes by optimising date labelling practices, enhancing packaging design to extend the storability of food, and providing on-pack information that helps consumers improve their food management capabilities.[454] For example, retailers like Tesco in the UK have already reformed many of their date labelling practices, removing best before dates from fruit and vegetable lines,[455] and removing use by dates from yoghurt lines.[456] To our

> Retailers can make impactful changes by optimising date labelling practices, enhancing packaging design to extend the storability of food, and providing on-pack information that helps consumers improve their food management capabilities.

knowledge, the effect of these changes on consumer behaviour has yet to be evaluated. Retailers also have the potential to influence choices consumers have about amounts purchased. Given that larger food packages sold in retail settings can lead to more food waste in households, offering smaller packages could help prevent food waste.[457] Retailers can also inadvertently cause customers to choose larger packaging over smaller alternatives in-store, with practices like "buy two – pay less" or the display of price per kilogram ratios potentially leading to consumers buying more or a larger package than they actually need.[457] Although it is often package designers at processors and manufacturers who make decisions around package sizes, given the considerable market power wielded by major supermarkets In New Zealand, these operators could hold sway in advocating for changes to packaging that prevent further food waste.

Altering pricing strategies is another avenue through which retailers can discourage the overbuying of food. By moving away from promotions such as 'buy one, get one free', which often lead to excessive buying and eventual waste,[458] retailers can adopt pricing models that incentivise the purchase of quantities that are more in line with consumer needs. Tailoring prices to discourage the overbuying of perishable products, for instance, has potential to significantly cut down on food waste at the consumer level.

Lastly, offering ready-made meals and recipe suggestions for products nearing their use by dates can encourage the use of food that would otherwise be discarded. This not only helps in reducing waste but also provides convenience for consumers looking for quick meal solutions.

Case study 12: Food marketing in retail – reaching consumers on food waste

A 2018 study by researchers from Scandinavia and the Netherlands highlighted how the actions and marketing strategies of retailers influence consumer behaviour around food waste.[454] The study introduces three case studies to show how three different retailers changed their practices to reduce food waste in conjunction with their customers:

ICA Resurskocken, Sweden

ICA Sweden, with a significant market share, introduced an in-store kitchen at their ICA Tuna store in Lund in 2007, utilising products that might otherwise be wasted. The kitchen aimed to offer quality meals at lower prices, largely targeting students and academics. The initiative helped reduce food wastage significantly, improved employee involvement, enhanced the store's image towards quality and sustainability, and received favourable media attention.

Rema1000, Denmark

A Norwegian retail chain operating in Denmark, Rema1000, decided to phase out multi-item offers (for example, 'buy one, get one free') in 2008 to reduce food waste. Initially, sales dropped in categories previously promoted through multi-item offers. However, this action received positive feedback from customers and improved the retailer's reputation, potentially influencing competitors to adopt similar strategies.

Intermarché, France

In 2014, Intermarché, a large French retailer, launched a campaign promoting the sale of imperfect fruits and vegetables at a 30% reduced price. The campaign aimed to increase awareness about food waste. The campaign increased store traffic, especially in the fruit and vegetable section, and led to higher sales volumes. It also prompted competitors to undertake similar actions and received extensive publicity and social media attention.

In Aotearoa, an uptick in ready-made meals sold by major retailers can be partially attributed to the rise of meal kit providers like My Food Bag, Woop, Bargain Box, and Hello Fresh.[30] While the Commerce Commission has classed meal kit providers as retailers,[392] these businesses straddle the line between being retailers and food service providers. On the one hand, they sell raw food products (and sometimes other groceries) directly to consumers, much like a retailer.[*,392] On the other hand, they share characteristics with food service providers because they handle, prepare, and portion food ingredients, which enables easier at home cooking. Understanding both of these characteristics can help us think about food waste in relation to meal kit providers. There is little known about food lost during meal kit processing and packaging;[459] we explore food waste within households using these services in section 6.1.2.[30]

Food waste in households: the role of food delivery services

Getting takeaways has always been a way to bring hospitality into the home. In 2016, the dominant form of food delivery globally (approximately 90% market share[460]) was via the 'traditional' model, whereby the consumer places an order with their local pizza place or restaurant and waits for the food service provider to deliver food to the door. However, the emergence of third party delivery apps has been reshaping this market, with food delivery apps and platforms (henceforth 'food delivery services') taking up an increasing market share.[461] From a food waste perspective, this likely shifts more waste from restaurant plates into households. While we discuss interventions to prevent household food waste in detail in section 6.2, here we highlight how food delivery services could influence patterns of household waste.

Food delivery services have been a growing segment of the hospitality industry globally[462] and in New Zealand.[463] In New Zealand, a number of digital platforms enable delivery of restaurant foods to households, with competition among apps like Delivereasy, DoorDash, Menulog,[†] Uber Eats, and Yummi.[464] As discussed in section 5.1.2, the food service sector generates food waste in New Zealand, but we know little about the relative contribution of different food service providers to our FLW problem. For food delivery services, this data gap reflects a global lack of study around food waste in this sector.[465]

The extent to which food delivery services contribute to overall FLW is a matter of debate, as it is not clear whether household food waste is counteracted by improved preparation efficiencies within restaurants or other food service providers.[466] On the one hand, researchers suggest that food delivery services can cause consumers to order more food than necessary. Over-ordering is influenced by several factors,[466] including the ease of access and variety of options available, promotional strategies and discounts used by food delivery apps (for example, setting a minimum price for free delivery)[467] and a lack of physical cues that might deter over purchasing in a traditional dining or shopping setting (i.e. consumers do not see physical portion sizes clearly when ordering digitally),[465] as well as positive attitudes and social approval towards these apps.[466] On the other hand, food delivery services may reduce preparation waste within service providers, as

The extent to which food delivery services contribute to overall FLW is a matter of debate, as it is not clear whether household food waste is counteracted by improved preparation efficiencies within restaurants or other food service providers.

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[*] According to the Commerce Commission, while major retailers perceive meal kit companies like My Food Bag and Hello Fresh as competitors, their respective turnovers are orders of magnitude apart, with retailers dominating the market. In late 2023, My Food Bag's annual turnover was an estimated $175 million, a fraction of Foodstuffs North Island's $4.3 billion for the same time period. The Commission suggests that meal kit providers are unlikely to provide strong competition to retailers for consumers' total grocery spend in the foreseeable future.

[†] Founded in Australia in 2006, Menulog operated in New Zealand from 2012 to 2024.

apps enable more accurate order matching based on real time availability of menu items, better demand prediction from consumer preference and ordering pattern data, personalised recommendations, and optimised delivery schedules.[468]

Given the relatively recent emergence of food delivery services and concomitant lack of study, we are yet to have a good understanding of FLW related to these services, making it difficult to design interventions. This is a feature of FLW across many parts of the supply chain (see section 2.3.1). As such, there is a clear need for further study of FLW within and caused by food delivery services.

> …there is a clear need for further study of FLW within and caused by food delivery services.

5.2.4 Prevention efforts: involving retailers and food service providers in system-wide initiatives

As we introduced in section 2.2.6, collaboration across the supply chain is fundamental to reducing FLW. Voluntary agreements and commitments that commit signatories to specific actions to reduce FLW are commonly used to foster collaboration among stakeholders, including retailers and the food service sector. Listed below are several examples of such initiatives, which typically provide frameworks for sharing best practices, monitoring progress, and publicly reporting on achievements in FLW reduction.

The Courtauld Commitment 2030 (UK)

This is a voluntary agreement aimed at improving resource efficiency and reducing waste within the UK food and drink sector. Building on the work by WRAP started in 2005,[401] the agreement involves various stakeholders, including major supermarkets, brand owners, and manufacturers. Participants commit to measurable goals such as reducing food and drink waste by 50% per capita by 2030 (relative to the UK 2007 baseline), as well as decreasing greenhouse gas intensity, and improving packaging design to minimise waste. The Food Waste Reduction Roadmap[469] supports the delivery of the Courtauld Commitment 2030 food waste target and is supported by all the largest grocery retailers in the UK (whose cumulative business represents 97% market share). Based on data from seven major retailers,[469] the average quantity of food going to waste per tonne of food handled in 2021 was 0.44% (i.e. 4.4 kilogram for every tonne handled), a reduction of approximately 18% on 2018 levels.[*] For the fifteen retailers who had comparable tonnage data for 2018 and 2021, food waste fell by over 19,000 tonnes, a decrease of 8%.[469]

The US Food Loss and Waste 2030 Champions

The US Food Loss and Waste 2030 Champions are businesses and organisations from across the supply chain that have publicly committed to reduce FLW in their own operations in the US by 50% by the year 2030.[470] Initiated by a coalition between the US Department of Agriculture (USDA) and US Environmental Protection Agency (EPA) in 2016,[471] the group consists of more than 45 organisations, many of whom are retailers (for example, Aldi, Amazon, Hello Fresh, Kroger, Walmart and more) and major food service businesses (such as Starbucks and Wendy's). The quantifiable successes for individual companies can vary widely, as each participant is at different stages of implementing their food waste reduction strategies.[†] Notable examples of success include Walmart's

[*] Based on WRAP's guidelines for retailers, we assume these estimates meet the definition for FLW prevention as defined by this report, as diversion destinations in the UK such as compost and anaerobic digestion are classed as waste destinations, while food redistribution data are reported separately.

[†] Notably, the initiative does not frequently release detailed collective results, instead presenting individual success stories and case studies highlighted by the EPA. As such, data on the wider impact of this initiative is

2018 reduction of food waste in their fresh departments by 90 million units of food, Kroger's improvement of food waste diversion from landfill from 2017 (27% of food waste diverted) to 2018 (40% diverted), and Aldi's diversion of 74% of their operational waste in 2021.[472]

Australian Food Pact

Since its launch in 2021, the Australian Food Pact has seen 32 businesses commit to halving their food waste by 2030. Signatories to the Pact include major retailers Coles and Woolworths, who together hold around 65% of the grocery market share.[473] In their first year of reporting, signatories sent more than 54 million meals to food rescue charities.[474]

Kai Commitment (New Zealand)

As highlighted in case study 2, the Kai Commitment is a voluntary agreement for New Zealand businesses to reduce FLW and related emissions across New Zealand's food supply chain.[114] The initiative, launched in late 2022, currently has eight signatories, including Foodstuffs NZ and Woolworths NZ, whose combined business likely accounts for more than three quarters of the grocery market in Aotearoa.[392]

While voluntary agreements have seen success in reducing FLW, there are also instances where governments pass laws and institute regulations that specifically target food waste. Targeting the food service and retail sector, France's legislation to reduce food waste in supermarkets and restaurants by diverting food waste from landfill is one of the better-known examples. Often described as a landfill ban for food waste, the policy is in fact more nuanced, as described in case study 13. Whether such an approach in Aotearoa would prevent food waste is unclear; in the French case, there was an increase in food rescue, suggesting there remains scope for prevention activities. France is not the only country to consider or implement policies to prevent food waste going to landfill, with a host of countries, states, and cities adopting a range of approaches. We summarise these policies in annex 2.

lacking. Additionally, many of the successes listed by the initiative relate to food waste diversion, rather than prevention as defined by this report.

Case study 13: France takes a unique approach to retail and food service waste

In 2016, France made international headlines[377] with the adoption of a groundbreaking law aimed at combatting food waste, particularly in the retail sector. The legislation, the first of its kind globally, prohibited[*] supermarkets from destroying unsold food products, compelling them to donate these items instead. To enact this, supermarkets larger than 400 square meters were required to enter partnerships with food rescue organisations to facilitate the donation of surplus food. Under these partnerships, supermarkets are expected to sort produce and donate packaged items 48 hours before their expiration dates, improving the quality of donated food. [475] In 2019, these measures were extended to the mass catering businesses (who produce more than 3,000 meals a day) and food industry (whose annual turnover exceeds €50 million), with both sectors banned from destroying unsold food products fit for consumption. Under these partnerships, supermarkets are expected to sort produce and donate packaged items 48 hours before their expiration dates, improving the quality of donated food.[475] In addition, commercial catering sectors were obliged to offer doggy bag options for their catering services. In 2020, fines for destroying unsold food fit for consumption were strengthened, increasing from €3,705 to the equivalent of 0.1% of a company's annual turnover. In addition, 'best before' dates and 'use by' dates had to be integrated into product codification to optimise logistics.[476]

The impacts of these laws have been notable. Following their implementation, food donations from supermarkets have increased significantly, with some reporting suggesting that donations rose by 30% in 2017, with more than 90% of supermarkets donating unsold food.[477] However, the implementation of these regulations has not been without shortcomings. Critics argue that the increase in food donations was not matched by an influx of funding or infrastructure to handle the dramatic uptick in donations, posing a challenge for food rescue organisations and resulting in waste redistribution rather than complete diversion.[477] Additionally, the law does not specify the quantities or proportion of unsold food that must be donated, making a 1% donation theoretically sufficient to meet legal obligations.[476] However, companies are also legally obligated to publicly display their food waste commitments. Additionally, the law has sparked a broader conversation about the need to prevent unnecessary food production in the first place.[475] As noted in section 1.1, food donation falls outside the definitional boundary of prevention used in this report. As such, in this context, French laws around RFS waste are more aligned with food rescue work (see *Food rescue in 2022: Where to from here?*).

[*] The degree to which this the law is prohibitive is debated, with some arguing the law promotes responsible corporate behaviour and formalises the expectation of donating food, rather than outright banning of food waste.

6. Household

Figure 34: A simplified depiction of the food supply chain highlighting the household stage.

In this section, we focus on the last stage of our simplified supply chain (see figure 34) and discuss food waste in households. The food supply chain exists to bring food to consumers. While this objective is met at the RFS stage (see section 5), a significant proportion of the food produced is intended to be prepared and eaten in homes.[57] A household can be one person who lives alone, or a group of people who share living spaces and may pool resources – including food – collectively.[478] What a household looks like varies significantly depending on circumstances and a range of factors such as age, geography, socio-economics, and cultural norms. Whereas 'consumers' refers to the individual people who purchase goods or services for their personal use, we use the term 'households' to refer to the private dwellings where food is being stored, prepared, and eaten.

Much research on household food waste is dedicated to understanding and modifying decision making processes and subsequent behaviours of consumers. Consumers' behaviours are related to many factors, including cultural attitudes around 'food' and 'waste', knowledge and beliefs about waste, and how easy or difficult avoiding waste is – or how easy or difficult consumers perceive avoiding waste to be.[479] Food and food waste in households can be complex and deeply personal, while also subject to social norms and expectations. Importantly, some of the reasons for behaviour can be external to the individual, such as social norms, available waste management infrastructure, and retail environments.[479,480] Additionally, behaviours and the reasons for them are not static; stability at home, stress, and difficulty can all influence how easy it is for an individual to maintain behaviour change.[439] Importantly, any interventions aimed at changing behaviour are not always contextually and culturally transferable.

Food and food waste in households can be complex and deeply personal, while also subject to social norms and expectations.

While behaviour change campaigns can produce results at the household level, which is considered the part of the supply chain where the most FLW occurs, an excessive focus on consumers can unfairly place responsibility for FLW on individuals and households and detract from more systemic action by actors with relatively more power to effect change. Therefore, consumer behaviour change interventions should be included as part of a suite of solutions, which holds stakeholders appropriately responsible for reducing FLW.

...an excessive focus on consumers can unfairly place responsibility for FLW on individuals and households and detract from more systemic action by actors with relatively more power to effect change.

6.1 Understanding household food waste

In households, food waste includes parts of food that are bought, received, or harvested and possibly processed or stored, but are not consumed and eventually discarded. Not all parts of food brought into the home can or will be eaten, and so we categorise the resulting food waste according to whether it is avoidable, potentially avoidable, or unavoidable:

- Avoidable: edible food that could have been consumed at some point.[481]
- Potentially avoidable: parts of food that are eaten by some people and not others (like bread crusts), or that is eaten in some food preparations and not others (like potato skins).[481]
- Unavoidable: inedible parts of food such as eggshells and bones, as well as parts of food most members of a population would not eat, like banana skins.[481]

As this report is focused on prevention, we are particularly interested in waste that is avoidable or potentially avoidable. However, there is some subjectivity around what parts of food may be edible or inedible and so nuance is needed categorising what waste is avoidable, potentially avoidable, or unavoidable – these are broad, general categories rather than fixed.

Good data is needed to identify areas that need intervention and can act as a benchmark to track the effectiveness of food waste prevention strategies, while standardisation can also help with comparison and monitoring progress over time. In the Food Waste Index Report 2021 the UNEP highlighted New Zealand and 13 other countries with high-quality data for household food waste estimates.[482] Annex 4 summarises how data was collected in these countries.

…there is some subjectivity around what parts of food may be edible or inedible and so nuance is needed categorising what waste is avoidable, potentially avoidable, or unavoidable…

6.1.1 How much food do New Zealand households waste?

A significant amount of FLW across the food supply chain occurs in households. Internationally, the percentage of total FLW that comes from households has been estimated at 32% in Australia,[57] and 40% (2019)-60% (2022) in the US.[401,483] In Aotearoa, the best estimate is 40%.[211] Because of differences in classifications and data collection methods, it can be challenging to make comparisons between these numbers. However, it seems reasonable to say that attention to household food waste has the potential to contribute to a substantial overall reduction in New Zealand's FLW. A recent estimate suggests food waste is costing around $1,500 per year per household in New Zealand, while in Australia, 71% of food that entered the market was intended for households, and approximately 18% of this purchased food was wasted.[57]

A recent estimate suggests food waste is costing around $1,500 per year per household in New Zealand…

In addition to the proportion of all our FLW that comes from households, we also have estimates of the amount of food that is wasted by New Zealand households. WasteMINZ has conducted two bin audits. In 2015, data from 1,402 household was used to conclude that approximately 230,000 tonnes of food is disposed of in kerbside collection across Aotearoa annually, or almost 150 kilograms per household.[484] In 2018, the audit was repeated on households in about half of the territorial authorities that were included in the 2015 audit, resulting in a sample of almost 600 households.

This study estimated that nationally nearly 300,000[*] tonnes of household food waste is sent to landfill annually, or about 164 kilograms per household.[403] The increase in the amount of food waste per household was partly attributed to one of the territorial authorities that was included in 2015, but not 2018, having separate food scraps bins destined for compost that were not counted. This biased the 2015 overall estimate downwards compared to 2018 when this territorial authority was not included, and illustrates the challenges of gathering reliable data. A strength of these estimates is that they involved direct measurement of waste by bin audit. However, as the authors of the report on the 2018 study acknowledge, the estimates are based on extrapolating from a sample of unknown representativeness of the New Zealand population. However, these estimates are broadly consistent with an analysis of secondary data that estimated 224,000 tonnes of food waste was sent to landfill by New Zealand households in 2011.[256]

As described earlier, not all household food waste is avoidable (see section 6.1). In the 2015 bin audits, 35% of New Zealand households' food waste was unavoidable, while 54% was avoidable and 12% potentially avoidable.[484] In 2018, 34% of household food waste was considered avoidable, 53% unavoidable, and 14% potentially unavoidable.[†,403] Differences between the two years were not statistically different from zero.[403] Similar to what we see internationally in Australia,[57] China,[485] and the EU,[479,486,487] in Aotearoa, self-reported data[488] and bin audits[403] show bread, fruit, and vegetables as the most prominent categories of avoidable food waste.

Bin audits are useful because they can potentially be linked to surveys and other household characteristic data, and they can provide detailed information on the contents of food waste, for example, the type of food wasted and whether its waste was avoidable. This level of detail can allow identification of potentially high impact targets for intervention and is also useful for evaluation. However, it is a resource intensive method of data collection, meaning it is infeasible for nationwide or ongoing data collection.

> … bread, fruit, and vegetables [are] the most prominent categories of avoidable food waste.

For ongoing monitoring, other data is available – territorial authorities are required to report to MfE the amount of food waste or food and organic waste combined that households leave for kerbside collection.[489] This data is not as granular as bin audits, but provides a nationwide picture of the amount of food waste at the level of the territorial authority, which is useful for ongoing monitoring. A gap in this data is that in territorial authorities where waste is collected privately rather than directly by the council, there is as yet no requirement for reporting.[490] It is also theoretically possible to collect and report this data at a smaller geographic level than the territorial authority.

> …territorial authorities are required to report to MfE the amount of food waste or food and organic waste combined that households leave for kerbside collection.

Another approach to studying household food waste is to ask people about the amount of food of which they dispose. This has the advantage of being far less resource intensive than actually measuring household waste.

[*] The most recent Food Waste Index Report (2024) from UNEP used the same bin audit to report the annual total amount of food disposed of by New Zealand households as just over 315,000 tonnes per year. It is not clear how this figure was derived by UNEP but one possibility is they used the bin audit's per capita or per household figures and applied them to Census population data that has been updated since the original bin audit was published.

[†] Percentages don't add to 100% because of rounding.

However, it can be subjective, inaccurate, or both. In a survey carried out alongside WasteMINZ's 2018 bin audits, respondents were asked whether the food they threw away was none, hardly any, a small amount, some, a reasonable amount, or a lot.[403] The measured waste, in kilograms per household per week, was about the same for those who responded "a small amount" and "some", and was more for these categories than households who responded "a reasonable amount". Subjectivity can be removed by asking households to estimate actual quantities – for example, one programme evaluation used the number of two litre ice cream containers[491] – but such measures may still be inaccurate due to respondents guessing rather than measuring, or reporting low levels of waste due to social desirability bias.

6.1.2 Drivers of food waste in households

Household food waste involves numerous behavioural, environmental, and socio-cultural factors.[480] These factors are interconnected, as shown in figure 35.[479,480] Importantly, the specific influences will vary from household to household.

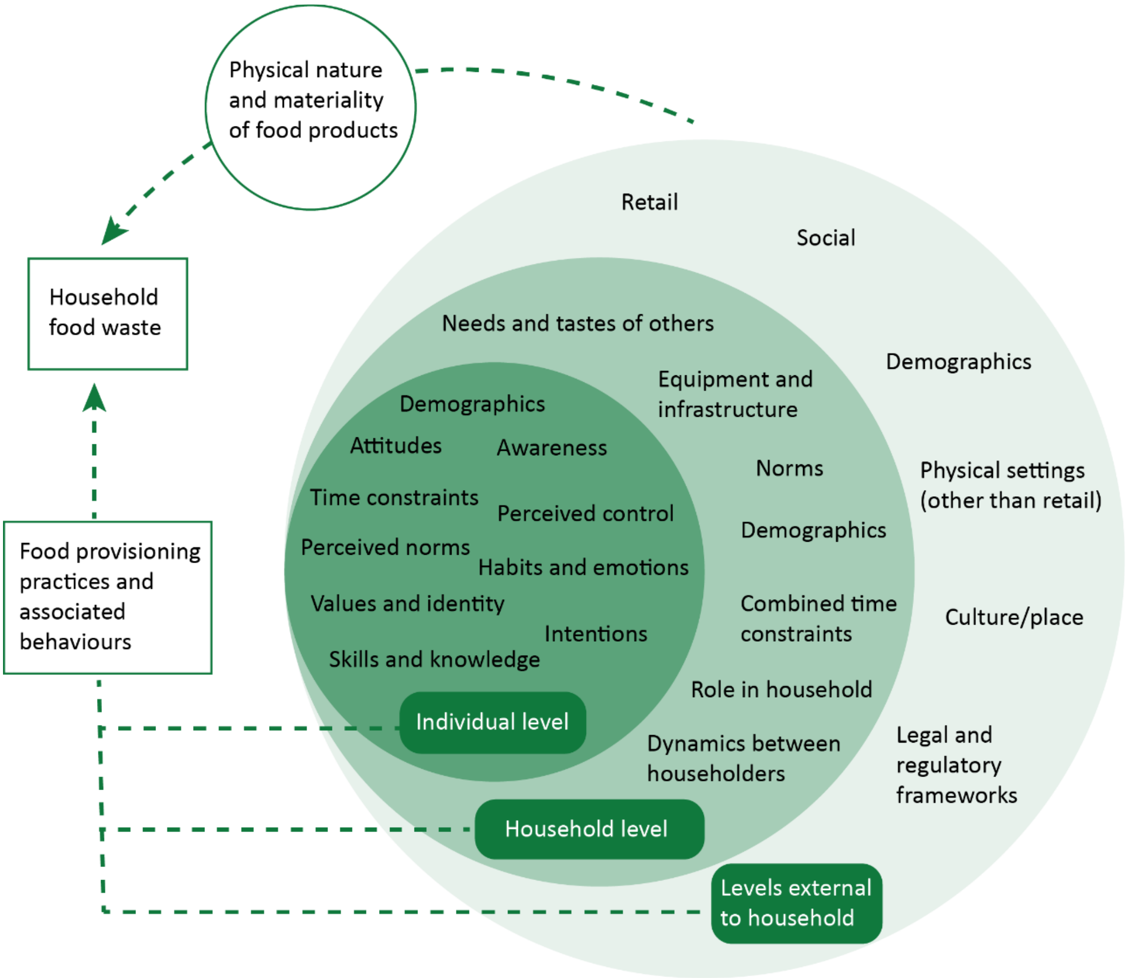

Figure 35: Influences on consumer behaviour and household food waste happen at various interconnected levels. Image credit: Boulet et al.[480]

To simplify our discussion of the drivers of food waste in households, we look at the issue in two ways. Firstly, we look at household characteristics, like demographics and attitudes, and how these might be related to different patterns of food waste.[492] Then, we look at the different stages of food's journey through the household, focusing on three stages: 1) planning and purchasing, 2) storage and preparation, 3) consumption and leftovers.[394]

There is considerable diversity in the composition of New Zealand households. According to the 2018 census,* 40% of households have children, 23% of households are one person, and 28% of households are couples or couples and other persons.[478] The population also has considerable ethnic and cultural diversity, as well as diversity in the locations of our households from cities to towns to rural locations. These and other characteristics are related to patterns of household food waste.

Different cultural traditions can lead to different patterns of food waste. For example, some cultures tend to serve food 'family style' where everyone serves themselves from a shared bowl, while in other cultures individual portions are served. We don't know of any studies that look at whether these styles result in different levels of waste in the home, but in hospitality settings, eating family style may be associated with more waste than individual servings.[493] Another example pertains to the social acceptability of finishing all food served; in Abu Dhabi it is considered inappropriate to finish all the food on a plate while in Japan it is the opposite.[494]

Figure 36 shows data from the Organisation for Economic Cooperation and Development (OECD) on how often different types of households – those with and without children, and earning high and low incomes – wasted food for various reasons. For each reason for waste, households with children are at least twice as likely to waste food as households without children.[495] In contrast, differences in waste between households in the highest and lowest income quintiles were less pronounced, although high income households were more likely than low income households to report wasting food because "too little was left to save", they "did not like or tired of eating" the food, and they were "unable to store or save" the food.[495] In general, there is some conflict in the literature over whether households at different incomes have different levels of food waste; although high income households may be less affected by the financial cost of food waste, low income households do waste food and sometimes provide abundant food to avoid the stigma of being identified as 'poor'.[479]

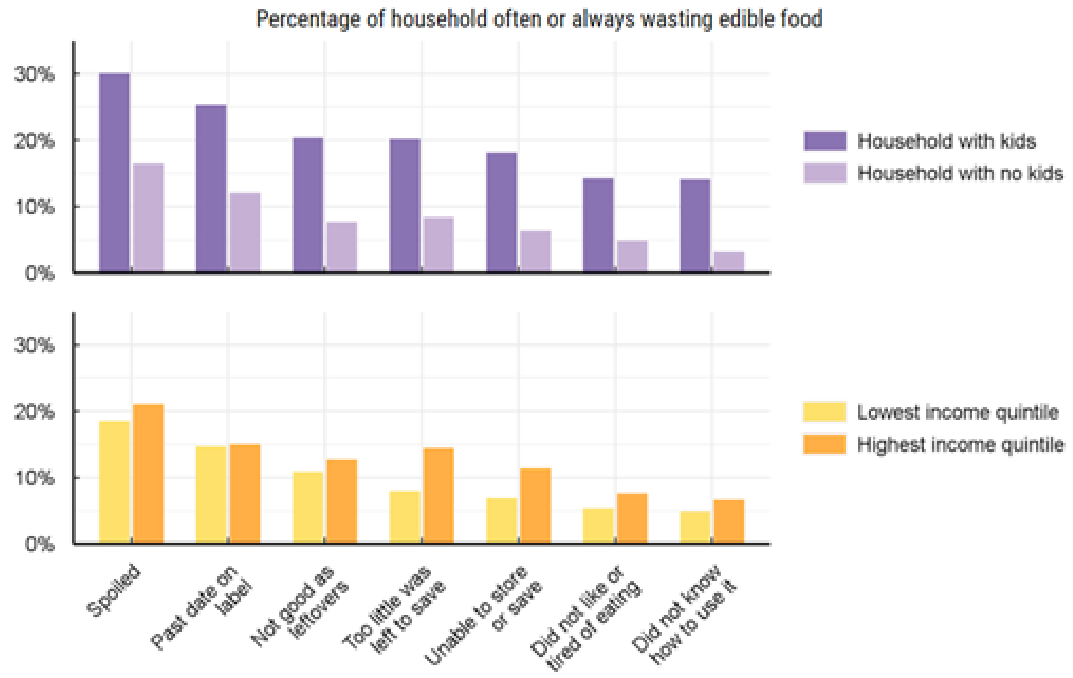

Figure 36: Food waste in households when factoring for children and income. These survey responses are compiled from nine countries in the OECD from the Environmental Policies and Individual Behaviour Change Survey. Image credit: OECD.[495]

* Data from the 2023 Census was not available at the time of writing.

An Australian study used survey data on food shopping, preparation, and waste habits to divide respondents into three categories in relation to food waste: ‘considerate planners’ who planned their shopping and cooking and rarely prepared food that went uneaten; ‘over providers’ who planned ahead but often prepared food that went uneaten; and ‘under planners’ who didn't generally plan ahead and produced more waste than ‘considerate planners’ but less waste than ‘over providers’.[496] One of the main predictors of being an ‘over provider’ was having children; parents provided more food than was needed in response to unpredictable preferences of children.[496]

As well as ensuring sufficient food for children, waste resulting from preparing too much food can result from cultural or social values that prioritise showing hospitality to guests by having abundant food available, and spending time with guests rather than preserving leftovers for future use.[497] Providing more food than guests are likely to eat can be motivated by a desire to avoid embarrassment, guilt, or perceived stigma related to the possibility of running out of food.[498-500] More generally, some people value being perceived as a ‘good provider’ by offering abundant food both to their own household and to guests.[501]

Finally, age and geography may play a role. Older people may be less likely to waste food because of moral concerns around wastefulness and experiences of food scarcity earlier in life;[479] for example, resulting from rationing in the aftermath of the second World War. European research suggests a relationship between geography and household food waste, with households in urban locations tending to waste more food than those in rural areas.[502]

> …waste resulting from preparing too much food can result from cultural or social values that prioritise showing hospitality to guests by having abundant food available…

Stages where household food waste can occur

Planning and purchasing

We combine planning and purchasing because they are closely related – many of the actions related to planning go on to affect purchasing. Actions at this stage include meal planning, making shopping lists, and shopping. People who plan their weekly menus are less likely to overstock than those who don't,[503,504] while those who don’t check fridges, freezers, and pantries before shopping often buy food they already have.[505] Shopping habits such as buying in bulk tend to create more food waste, whereas those who stick to a list produce less food waste.[506]

Lack of time, energy, and money in busy lives have been identified as barriers to planning.[507] There is an ever increasing demand for convenience, with consumers wanting to minimise inconvenience while valuing flexibility and choice.[508] This can sometimes cause trade-offs with waste preventative behaviours such as planning or keeping and eating leftovers.[479]

As well as planning, features of the shopping environment can shape waste behaviours. People who shop at large supermarket chains tend to have larger amounts of food waste than those who grow their own food or buy from small shops or local markets.[509] As discussed in section 5.2.3, marketing strategies employed by retailers, such as ‘buy one, get one free’ can encourage consumers to buy more than they need,[504] and the positioning of products on shelves for children's snack foods may also promote excess, unnecessary purchasing, and wasteful behaviours.[510]

There is some evidence suggesting less food is wasted when cooking with a meal kit – that is, recipes and pre-portioned ingredients for a set number of meals delivered to the home – than when cooking with ingredients sourced from a supermarket.[511] Using meal kits can aid with proper portioning, reducing over purchasing and impulsive buying. Survey data from 955 households from six counties across Europe and North America suggests that meal kits can reduce food waste in comparison to traditionally cooked meals by up to 38%.[512] Similarly, a life cycle assessment of meal kits in the US found they had lower average greenhouse gas emissions than equivalent grocery store meals.[459] In addition, the study inferred that because grocery meals are not pre-portioned, they result in higher food waste in households. However, the study also noted that meal kits have higher packaging impacts than grocery meals. In addition to packaging problems, in New Zealand, meal kits are typically more expensive than shopping for the equivalent products in a supermarket,[392,513] although brands like Bargain Box[514] are trying to minimise this difference.

People who shop at large supermarket chains tend to have larger amounts of food waste than those who grow their own food or buy from small shops or local markets.

Storage and preparation

During storage and preparation, knowledge of food safety and cooking or preservation techniques can influence food waste generation. Proper storage, such as in the fridge or freezer, can prolong the shelf life of foods, while improper storage accelerates food spoilage.[394] Tomatoes, for example, should be stored stem side down, and in a bag in the fridge if they are ripe.[515] Studies have highlighted a lack of knowledge around storage, such as the optimal fridge temperature, and low confidence in food management skills, as important factors.[504,510] In a survey in Aotearoa, Gen Y and Gen Z respondents reported not knowing how to store food as a reason for their own food waste.[488]

Food waste in the preparation stage can result from discarding what is inedible or perceived as undesirable (such as broccoli stalks or potato skins), as well as from preparation techniques that may not make effective use of food (such as, by discarding a large amount of apple when removing the core).[78,504] Food can also be rendered inedible or become unpalatable during preparation due to a lack of cooking skills (such as by burning or over-seasoning), resulting in food waste.

Consumption and leftovers

Food that is prepared but not eaten, referred to as leftovers, can be plate waste, surplus meals, leftover ingredients from food preparation, or food leftover from a hospitality setting brought home in a doggy bag.[516] Leftovers are not inherently food waste; cooking enough food for multiple meals is a common practice to maximise efficiency and convenience in food preparation.[479] However, the 2018 WasteMINZ bin audits estimated that leftovers accounted for 8.2% of the avoidable food waste by weight generated by New Zealanders and was the second largest type of avoidable food waste after bread.[403]

Wasted leftovers may be a sign of not knowing how to portion food appropriately.[479] Some of the social and

Leftovers are not inherently food waste; cooking enough food for multiple meals is a common practice to maximise efficiency and convenience in food preparation.

cultural considerations described above, such as a desire to be a good provider or a generous host, come into play at this stage.

6.2 How can we prevent food waste in households?

As a framework for thinking about ways to prevent food waste in households we draw on a theory of change (ToC) developed by MfE.[517] The ToC is not specific to food waste but is about waste-related behaviour change more broadly. As we have emphasised the importance of a systems view throughout this report we focus on the macro level of the ToC, but we acknowledge that meso level and micro level considerations (see figure 35) – including household and individual characteristics discussed in section 6.1.2 – will affect the success of any macro level intervention.

6.2.1 Promoting voluntary behaviour change

In New Zealand, promotions to reduce household food waste began around 2014 when WasteMINZ launched the National Food Waste Prevention Project, the first action being the 2015 audits as well as a nationally representative survey of 1,365 households about behaviours and attitudes that lead to food waste.[518] This research was followed by a three year 'Love Food Hate Waste' behaviour change multimedia campaign.[519] This campaign was an application of the highly successful version that has now been running in the UK for over 20 years.[111,520]

Information- and engagement-based approaches

Providing information is probably the most common intervention to promote behaviour change. In general, 'information deficit theory' – the assumption that people don't know their behaviour is sub-optimal and that providing more information will change behaviour – is not supported by the evidence.[521] MfE's literature review on reducing household food waste concluded that, on its own, information sharing is ineffective.[394] In contrast, in the US, ReFED estimates that consumer education campaigns can achieve the greatest net financial benefit of all consumer focused interventions, at US$17 billion.[424] Information can be made more effective by considering the way it is conveyed, who it is conveyed by, and the prevailing norms around 'common knowledge'.[522] To the degree that a lack of knowledge is the problem, providing information on how to store food and improving cooking skills are the knowledge gaps aligned with the drivers of food waste identified in section 6.1.2.

Though awareness campaigns have received the most attention internationally – particularly across Canada, the UK, and the US – Love Food Hate Waste in the UK estimates that information campaigns in combination with face-to-face activities such as cooking courses can achieve around a 15% reduction in avoidable household food waste.[523,524]

Gamification has also been shown to reduce self-reported food waste, although it had no effect on food waste measured by bin audit.[525] There is the potential limitation of only meaningfully engaging with those who voluntarily sign up and reaching self-selected people who choose to participate. Targeted recruitment efforts could be considered to address this.

Love Food Hate Waste in the UK estimates that information campaigns in combination with face-to-face activities such as cooking courses can achieve around a 15% reduction in avoidable household food waste.

Awareness building campaigns use planned activities or communications over a period of time, typically aimed to appeal to many people.[523] Such campaigns can operate at a variety of scales, from global campaigns such as 'Think. Eat. Save' spearheaded by the UNEP and FAO, to council led challenges (see annex 5). For example, Germany's 'Too good for the bin!' campaign by the Federal Ministry of Food and Agriculture of Germany started in 2012 and runs across the food supply chain. The activities as part of the campaign include a yearly awareness raising week, web resource, prizes for projects across five different categories, an app, social media content, and restaurant leftover boxes. The effectiveness of 'Too good for the bin!' is being evaluated with annual measures of consumer knowledge and attitudes, as well as measurement and reporting of food waste.[526] The New Zealand version of the international Love Food Hate Waste campaigns have already established some food waste prevention activities like "Eat Me First" stickers and classes, and many councils are engaged and funding the programme.

The New Zealand version of the international Love Food Hate Waste campaigns have already established some food waste prevention activities like "Eat Me First" stickers and classes, and many councils are engaged and funding the programme.

As discussed in section 6.1.1, there can be a disconnect between how much food waste people think they produce and how much they actually produce. Measurement of food waste is effective at changing behaviour.[394] Awareness raising campaigns may prompt people to consider their food waste, even if they have limited effects on actual food waste behaviour.[525,527]

School programmes, which provide students with information and experiences outside of their own homes, present an opportunity to educate children and young people about food waste.[528] Promoting and building familiarity with imperfect produce, portion sizes, or cooking can help to normalise and reinforce prevention techniques that can then continue at home.[78] In school-based programmes in Australia that used a mix of educational, skills-based and whole school events, both students and parents were observed to display more of the targeted behaviours, showing that interventions in external settings can influence behaviours in homes.[529] In New Zealand, examples of school-based programmes include Garden to Table, which delivers food education for children,[530] and Enviroschools, where young people design and lead sustainability projects in their school and neighbourhood.[531]

Incorporating active engagement, for example, goal setting, feedback, and commitment making, can be more effective at changing behaviour than simply presenting information.[522] In the UK, a pilot run by WRAP with monthly workshops over four months achieved a reduction in avoidable food waste of more than 50% on average, based on estimated volume data by participants collected in the first and last week of the programme.[523] An example from Aotearoa is the Food Lovers Masterclass delivered by Waste-Ed with Kate with funding from councils, providing information, demonstration, and participation in food waste prevention techniques. With recent MfE funding to evaluate the classes' effectiveness, there are promising signals with almost half of participants reporting a reduction in the volume of food they waste since taking the class (see annex 5).[491]

Asking participants to make a commitment to a particular action is thought to promote adherence to their commitment and thereby behaviour change, with the evidence being mixed to positive in the short- and long-term.[532] A meta-analysis of commitment research showed that commitment with other treatments, such as feedback or incentives, was more effective than commitment alone, particularly for long-term change.[532] Processes such as self-concept, attitudes, and social and personal norms, are also thought to underlie the effectiveness of commitment making, particularly when commitments are made publicly and there is social pressure to adhere.[532] In 2022, Love Food Hate Waste in New Zealand ran a 'Food Waste Warriors challenge' that involved people signing up to participate in a series of food saving challenges with tips and resources to promote better storage, meal planning, and making the most of leftovers. An incentive of a pantry and fridge makeover, worth $1,500, was provided. Engagement on social media platforms were also promoted with prizes and giveaways.[533]

Approaches that make it easier for people to prevent waste

Behavioural scientists can draw on sophisticated understanding of human decision making to design behaviour change interventions.[534,535] Information and engagement-based interventions target our conscious decision making, but there are also interventions that target our unconscious or default decision making. Such interventions are known as 'nudges' and work by removing 'friction' – that is, things that make a given course of action harder – from the desired behaviour. While often effective, these types of interventions have been criticised for undermining personal autonomy,[536,537] although one study found participants generally approved of using nudges to encourage healthy eating.[538] Additionally, while policy makers may grapple with the potential ethical implications, some marketing companies and other commercial actors show no such compunction, creating 'sludges' – nudges that promote behaviour that is of no benefit or is even harmful to the individual.[539]

As discussed in section 5.2.3, retailers can have significant influence over consumers' purchasing decisions through the way products are laid out in-store and the promotions available. Retailers could use this influence to make it easier for consumers to purchase the right amount of food for their needs. This could mean, in collaboration with processors and manufacturers, making it simpler to buy individual pieces or small portions of some products with short shelf lives, as well as avoiding promotions that make it better value for money to buy more products with short shelf lives than are needed (see section 5.2.3). Changes to these practices are business decisions with potential implications for revenue; voluntary agreements like those discussed in section 5.2.4 may help with getting buy in from retailers.

> [I]nterventions … known as 'nudges' … work by removing 'friction' – that is, things that make a given course of action harder – from the desired behaviour. While often effective, these types of interventions have been criticised for undermining personal autonomy…

Friction can also be reduced with tools and technologies. These can be relatively simple, such as Love Food Hate Waste's "Eat Me First" stickers, which can be placed on shelves or specific food items as a visual cue.[540] They can also incorporate more advanced technologies. For example, smart fridges could prevent food waste by relaying images that enable consumers to confirm which products they already have to avoid duplicate purchases, or to send alerts about product expiry.[541] Research on smart fridge systems that guide users in food related activities such as storage and planning have been shown to increase awareness of food availability at home, use of food before expiration date, and have environmental and economic benefits based on life cycle analyses.[542,543] Other tools can be either high or low tech – for example, preventing waste by preparing the appropriate portion could be achieved with the help of simple measuring devices[544] or with technology-aided measurement as is used in smart scales.[545,546] Modifications to food labelling and packaging may also promote FLW prevention (see table 6 and section 4.2).

Multipronged interventions

Interventions that combine multiple elements are often more successful than single interventions, for example, combining awareness-raising and face-to-face activities are recommended by Love Food Hate Waste UK, discussed above.[523] A randomised controlled trial using a technology-aided measurement approach with personalised coaching collected data on food behaviours and waste through photos and informational tags of receipts, preparation waste, consumption, and storage purges, and found a 24% reduction on food wasted during dining.[546] Because there are multiple drivers of household food waste, it makes sense that multipronged interventions are more successful than those with a single focus.

Because there are multiple drivers of household food waste, it makes sense that multipronged interventions are more successful than those with a single focus.

Box 9: Date labelling

Date labels indicate when a product is either safe or best to eat.[547] A key issue is the distinction between 'use by' and 'best before' dates being misunderstood by consumers, resulting in food being thrown away when it has passed its best before date but is still edible.[405,359,548,357] European research suggests that between 10%-20% of food wasted is due to product date labelling and that only a third of EU consumers correctly interpret the meaning of the best before date.[369,549] In New Zealand there is evidence the public generally understands that food is still safe to eat even after the best before date has passed. Surveys in New Zealand have found high proportions of consumers understand the meaning of best before date labels, with only around 10% of people mistakenly believing food to be unsafe to eat after the best before date.[488,550] Similar proportions reported that they would dispose of food past its best before date.[488,550]

Understanding of what date labels mean and self-reported behaviour may not match actual behaviour, but there is little data available on actual behaviour. One clue may come from the 2018 bin audits. Of food that was disposed of in unopened packaging, 68% had passed its best before date prior to the study and 16% passed its best before date during the study. Because the food was thrown away unopened, it is unlikely that it was evaluated for potential spoilage before being disposed of. However, bin audits cannot tell us the actual reason for disposal of food, nor can they give us any insight into the universe of food in people's homes that is past its best before date and not disposed of. There would be benefit in more research into how date labelling affects food waste behaviour in Aotearoa.

While removing best before dates could prevent early discarding of food, it relies on the household members to be well-informed consumers. A consideration here is the value of education to enable better judgement of food that is safe to eat. Much date label reform internationally focuses on changing phrases on the label. However, many studies suggest that the differences in the intent to discard based on the specific label phrase is relatively insignificant, with the willingness to consume or waste a food product mainly mediated by perception of safety requiring that food is sometimes wasted regardless of the wording on the date label.[358,551-554] Consumers may also be more sensitive to the date rather than the wording, with an eye tracking study show consumers fixate significantly more on the date than on the phrase, and that 50% of discard decisions involving no visual fixation on the phrase. Evidence on the effectiveness of messaging strategies around date labels are still early in the research stages.[555]

6.2.2 Using policy as a tool to drive change at a system level

In Aotearoa, MfE has set strategic direction with the publication of a waste strategy for New Zealand focusing on circular and systems thinking to reduce the amount of waste we generate.[556] Overseas, similar strategies towards more sustainable models to prevent waste have been taken up by the EU,[557] Australia,[558] and Singapore.[559] Overarching national frameworks can provide direction to align regional and local initiatives, as well as support more effective collaborations across public and private sectors (see section 2.2.6).

> Overarching national frameworks can provide direction to align regional and local initiatives, as well as support more effective collaborations across public and private sectors.

The MfE strategy includes two components that are relevant for household food waste prevention. The first is the call for household food scraps collection to be available to all urban households in New Zealand by 2030.[556] While diverting food scraps from landfill is the primary purpose of food scraps collection and thus not itself prevention, there is some evidence that separating food scraps from other household waste may lead to prevention in the long-term as the process of separating makes food waste more visible and may therefore motivate households to take other preventive actions.[479] Whether this actually happens is contested.[560]

> ...there is some evidence that separating food scraps from other household waste may lead to prevention in the long-term as the process of separating makes food waste more visible and may therefore motivate households to take other preventive actions.

The Strategy also promotes legislation around planning and reporting on waste for central and local governments, with territorial authorities now obliged to report how much food waste is collected in dedicated food scrap containers, or combined food and garden waste collections.[489] This will enable prevention of household food waste by making it easy to monitor the amount of food waste households are generating, but see section 6.1.1 for a discussion of the limitations of this source of data.

Another policy lever available is the use of financial incentives or disincentives to encourage households to prevent food waste. Various 'polluter pays' models could be considered, with some overseas evidence suggesting higher collection fees may be effective at reducing people’s waste output.[561] For example, in Luxembourg, citizens who reduce their household waste are financially rewarded with reduced fees.[562] Weight-based billing systems appear to have significant effects on reducing waste, increased recycling rates has been observed in Sweden where municipalities implementing a weight-based billing system had 20% less household waste per capita than other municipalities.[563] In Aotearoa, 'pay as you throw' schemes have been used for general waste for residents in some Auckland suburbs but, residents in these suburbs produced more or less the same amount of waste as ratepayer funded rubbish collections.[561] In drawing lessons for policy making, it is important to note that these approaches were designed around overall household waste and not food waste specifically. However, in South Korea, a 'pay as you throw' scheme applies to food waste and anecdotal reports suggest the combination of the financial disincentive and the visualisation of the amount of waste produced has reduced food waste output.[564]

> [I]n Luxembourg, citizens who reduce their household waste are financially rewarded with reduced fees.

Policy makers can also lead on monitoring and evaluation.[528] Public data and reporting can be improved for accountability purposes at all levels of the supply chain. Better establishment of data management protocols can potentially enable sharing with protected confidentiality, and data dashboards for broader access and use. Data sources could also be expanded to include reporting, audits and tracking systems (at household or regional level – for example, through the collection of kerbside collection data), citizen science projects and product lifecycle assessments. Tracking could highlight potential areas of inequity for more targeted interventions or funding for prevention projects although there are potential unintended consequences and a need for principles around ethics, privacy, and transparency.

Policy action does not have to be top-down. Policy makers can support participatory approaches to reducing food waste. The European Commission has previously convened a citizens' panel on food waste to engage actors, strengthen collaboration, and make recommendations to help and guide member states in achieving food waste targets.[565] Policy makers can also support businesses and charities undertaking interventions that target voluntary behaviour change, as described in section 6.2.1. Involvement from policy makers may lead to better integration and coordination between high-level food waste policy, local or regional policy, and third sector actors, in turn resulting in better engagement, including the establishment of campaigns, knowledge hubs, and community led initiatives.[528]

MfE has recently continued to fund work on prevention of household food waste. The Waste Minimisation Fund provides financial support for projects that minimise materials, including food, being sent to landfill.[566] For example, the Dunedin City Council was supported for work delivering improved kerbside services (including food waste, organics, collection, and processing)[567] and the Whanganui Kai Hub[568] for providing a centralised place to redistribute food and run educational workshops. National food waste reduction programmes aim to reduce food waste in three settings, one of which is household food waste (the others being businesses and Māori led settings, which includes households in its scope). Projects funded under the National Food Waste Reduction Programmes relating to household food waste include the WasteMINZ Love Food Hate Waste campaign and Para Kore's 'Para Kai' programme, a Māori led kaupapa Māori initiative driving the reduction of food waste.[569]

6.2.3 Identifying and prioritising effective ways to prevent household food waste

It can be challenging to assess the effectiveness of interventions and policies intended to target food waste, because there is often not a convincing counterfactual.[570] Some of the more common barriers to creating a convincing counterfactual in interventions to prevent household food waste are:

- The lack of a control group without the intervention in some studies.
- Self-selection into interventions. People who are more motivated to reduce their food waste undertake the intervention and those who are less motivated don't, confounding the analysis of differences between the groups.[571]
- Multiple interventions are undertaken at the same time, so that it is hard to unravel which components, or combinations of components, are effective.[570]

Additionally, sometimes the trade-offs of different data collection methods (described in section 6.1.1) are evident in attempts to evaluate the success of interventions. While we may want to know the volume of food waste a household generated before and after an intervention, it is easier to find out if a household representative believes they waste less than they did before the intervention, or intends to reduce their food waste.

Even when robust evaluations provide evidence of an intervention's or policy's effectiveness overseas, policy makers and others will need to consider whether similar results are likely in New Zealand in the relevant local context.[572] Mixed methods evaluations that combine quantitative data and qualitative data can provide understanding of whether an intervention is effective and why it was effective, making it easier to determine the applicability of the findings in other contexts, and providing richer information than either approach alone.[573] Another consideration is whether it's feasible to scale up interventions[572] – for example, are there enough suitably trained people to deliver a class nationwide, or is it likely that a large share of households will purchase a smart fridge? As well as feasibility consideration, ReFED considers the potential of an intervention to make profit,[574] although profit potential is relevant only to some interventions targeting consumers, like those where retailers alter the shopping environment.

Ultimately, policy makers and others choosing which interventions to pursue need to prioritise. OzHarvest and Behaviour Works Australia, within the Monash Sustainable Development Institute at Monash University, conducted a systematic review of desired food waste behaviours to determine likely impact on food waste and a survey of 1,600 consumers to determine likelihood of adoption and used the results to create an impact-likelihood matrix (see figure 37) to prioritise target behaviours for campaigns and policy development.[575] The matrix divides behaviours into quadrants based on likelihood and impact, with high likelihood and high impact behaviours being priority behaviours, implying that policy attention and resource should be focused in this quadrant.[575] Interventions targeting behaviours in other quadrants are likely to be less effective in reducing food waste because the impact of the intervention on waste is small, because the underlying behaviour change is unlikely, or both.

Figure 37: Food waste reduction behaviour matrix. Image credit: OzHarvest.[575]

6.3 Households' role in preventing food loss and waste across the supply chain

As described in section 2.1, the dominant narrative is that in high income countries like Aotearoa, food waste primarily occurs at the consumer end of the supply chain, in contrast with low income countries where FLW happens earlier in the supply chain because of a lack of resources to invest in mechanisation and other technologies that both promote efficient supply chains and prevent FLW.[55,134] However, as we have described throughout this report, there are abundant opportunities to prevent FLW in the supply chain in addition to opportunities to prevent food waste in households. Importantly, some of the opportunities to prevent household food waste are upstream, in decisions made by processors, manufacturers, and retailers.[55,134]

…some of the opportunities to prevent household food waste are upstream, in decisions made by processors, manufacturers, and retailers.

While we should avoid holding consumers responsible for more than their fair share of FLW, we can recognise their potential power in preventing FLW. The supply chain exists to bring food to consumers. As such, consumers do have some power to prevent FLW, not only in their households, but across the supply chain. Consumer action has long been a tool to pursue social and political goals,[58] with relatively recent examples including boycotting products made in Apartheid South Africa[576,577] and the 'buycott' of certified Fair Trade products.[578] In its LTIB, MPI recognised the implications for New Zealand producers of growing consumer demand for sustainability in food supply chains.[38]

In its LTIB, MPI recognised the implications for New Zealand producers of growing consumer demand for sustainability in food supply chains.

Many of the actions we discuss in this section and throughout the report could strengthen consumer action. For example, robust data and monitoring systems would make it easier for consumers to identify products, which are aligned with their goals around FLW prevention, while awareness raising on the topic of FLW prevention could make it more likely that consumer action achieves a critical mass.

7. Research for food loss and waste prevention

Research and innovation is a key part of developing new ideas, technologies, and practices for preventing FLW throughout all stages of the supply chain. FLW prevention efforts will benefit most from applied research and experimental development, where innovations are developed, used, and evaluated for their efficacy.

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Businesses have varying capabilities and resources for innovation and research. Collaboration and the sharing of innovative practices are also in tension with maintaining competitive advantages. In addition, there are challenges in adoption, implementation, and evaluation of innovations. Industry led research collaborations, such as Australia's Cooperative Research Centres (CRCs), for example, End Food Waste (formerly Fight Food Waste CRC) (see box 10), have proved successful in creating partnerships between researchers, government, and industry to facilitate knowledge and data sharing and provide funding to look at innovation to reduce FLW.[579]

Box 10: The Australian Cooperative Research Centre model

In the early 1990s, the Australian Government set up CRCs as a separate funding programme in addition to the government owned research agency, the Commonwealth Scientific and Industrial Research Organisation (known as CSIRO). CRCs are government supported research programmes that provide public-private links across research and industry to promote high levels of adoption and commercialisation of science and are typically hosted by research organisations with government funding for a limited time. Australian CRCs are industry led incorporated entities funded through a combination of grants, commercial industry, and government-administered funding. Around 30% of CRC programme is contributed through government grants.[580] The governance structures of Australian CRCs have central government (Innovation and Science Australia) involvement in strategy, assessment, recommendations, and advice to ministers, while being actively managed with a significant degree of flexibility by a CRC management team from industry and research organisations.[580,581] Australian CRCs aim to solve industry problems as well as improving the competitiveness, productivity, and sustainability of Australian industries. Education and training (PhD) programmes in CRCs are also industry focused – to build capacity and capability, increase R&D capabilities (in SMEs), and encourage industry take-up of research.[582,579]

CRCs are a collaboration between at least one business and one research organisation, although many include tens of partners ranging from all levels of government, international partners, not-for-profits, multinational corporations, SMEs, industry and community associations, and universities. What were originally Fight Food Waste CRC and Stop Food Waste Australia merged to form End Food Waste Australia, one of the world’s largest public private partnerships involving more than 100 organisations.[583]

The CRC programme provides long-term funding for up to 10 years, and short-term funding, known as the CRC-P (project) stream, for up to three years. The CRC-P uses a matched funding model of grants between AU$100,000 and AU$3 million, and in collaboration with at least two Australian industry organisations, including one SME, as well as one Australian research organisation.[579]

Over 200 CRCs have been supported since 1991,[580] and currently there are 24 active CRCs across a wide range of topic areas including End Food Waste CRC, Food Agility CRC, and Future Food Systems CRC.

New Zealand has had a funding scheme conceptually similar to the CRC programme although more limited, the Partnerships Scheme. Its funding has been reduced and there have been no new Partnerships funded since 2018.[584]

7.1 The research and innovation landscape for food loss and waste prevention

In 2023, R&D spending by the primary sector totalled $139 million (just under 4% of New Zealand's total research spending) while $89 million was spent on R&D by the food manufacturing sector, with over 100 entities engaging in R&D in both sectors (9% of entities performing R&D in New Zealand).[*,585]

Given the small scale of New Zealand's research enterprise, leveraging existing research innovations, including from offshore, is essential.[586] In FLW prevention (see box 11), both adopting innovations and developing new practices or technologies are useful at all stages of the supply chain. There can, however, be trade-offs between developing or tailoring new innovative technologies versus leveraging already existing innovations, including costs of development versus adaptation and the expertise required.

Box 11: Government funding for research and innovation in food loss and waste prevention

Although significant research funding in New Zealand is directed towards research into food in its many dimensions, relatively little has been focused on FLW prevention. Three funding streams are particularly relevant.

- MfE has a Waste Minimisation Fund to accelerate New Zealand's transition towards a low emissions and low waste economy. There was over $120 million available in this fund for 2023 and 2024, which is funded through the Waste Disposal Levy. Funding is available for infrastructure and other enabling systems to reduce landfill emissions from organics waste, including diverting FLW. The minimum grant sizes are $50,000 for R&D, business cases, or innovation projects and $150,000 for all other project types.[566]
- MPI funds innovative projects in New Zealand's food and fibre sector through the SFF funding with about $60 million available each year through partnerships and grants, and has minimum co-investment requirements but no cap.[587] Commercially-oriented proposals will have a maximum of 40% of total cost contributed by MPI; for community-driven proposals MPI will contribute up to 50-60%; and proposals with public-good benefits may have up to 80% of costs contributed.[588] Projects must also demonstrate sustainable benefits to New Zealand (environmental, economic, social, or cultural).
- Callaghan Innovation provides grants for commercialisation of technology, focused on developing an innovation ecosystem or deep technology (for example, Ārohia Trailblazer[589] and deep tech incubators[590]). They also provide support for businesses to carry out R&D through early career researchers, to build their experiences in industry (covering 6 months of salary of graduate students – Masters and PhD[591] or internships for tertiary-level students),[591] and grants for companies to develop R&D capability.[592]

[*] As a comparator, the computer services industry was the sector with the largest R&D expenditure of over $1 billion (20% of total R&D spending in New Zealand) in 2023.

7.1.1 The contribution of business to food research and innovation

Businesses contributed 59% of total R&D spending in New Zealand in 2022. This percentage has significantly increased since 2010, when businesses contributed 40% of total national R&D spending. 23% of food, beverage, and tobacco manufacturing firms reported engagement in R&D in 2013 and 58% reported engaging in innovative activities, both figures higher than the New Zealand average (8% for R&D and 46% in innovation).[593] However, there has been a reduction in food manufacturing business reporting performing R&D to 18% in 2022.[586]

Large companies can spend significant amounts on R&D. Fonterra, for example, has had an R&D centre based in Palmerston North since 1927 and spends more than $80 million a year on R&D,[594] with plans to increase total annual R&D investment by over 50% to around $160 million per annum in 2030.[595]

7.1.2 Examples of public sector organisations that do research into FLW prevention

University based research groups in Aotearoa, most notably the UoO's Food Waste Innovation research group, lead FLW initiatives and also work collaboratively across the public and private sector. The Food Waste Innovation research group has been involved in measuring FLW, developing reduction strategies, developing technology for producers to reduce FLW, and studying techniques to influence consumer behaviour change.[596]

AgResearch has a focus area on sustainable farming systems, climate change, and transformation (including a circular bioeconomy model for maximising value while minimising waste from production through to consumption by quantification and evaluation of resource flows through food systems), as well as piloting new technologies to prevent and repurpose waste.[597]

Plant & Food Research has a 'smart food systems' research theme that includes developing tools that track food along the supply chain through sensing technologies, and how by-products from production can be used in innovative ways.[598] They have also carried out a mapping study on organic waste in the Marlborough, Nelson, and Tasman regions to identify the available biomaterial and the potential for bio-waste reuse or upcycling.[599]

7.1.3 Collaboration between industry and research is vital for sector impact

New Zealand's food and beverage industry accounts for almost half of all goods and service exports[600] and software-as-a-service is currently growing by 16% annually and could become a major industry for Aotearoa.[601] Combining these industries could create an economic niche for New Zealand.[601] In the New Zealand agricultural sector, AgriTech New Zealand takes a key role in developing the technology ecosystem for agricultural applications – connecting researchers, innovators, investors, regulators, and enablers.[602] It is difficult for technology companies to reach a viable scale within Aotearoa due to the size of the market; therefore, catering to the export market is generally necessary for New Zealand businesses. However, in agri-tech there is a trade-off between maintaining competitive advantage in New Zealand's food industry against overseas companies through innovation and technology, particularly in dairy and farming, versus the profits from exporting innovations or technology overseas. Agri-tech that is developed to prevent FLW, however, could be a technology that does not undercut New Zealand's own industry and can also be exported.

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The relevant technology transfer system in New Zealand encompasses industry bodies (such as DairyNZ, Beef + Lamb New Zealand, HortNZ, Seafood New Zealand, Aquaculture New Zealand, and the New Zealand Forest Owners Association), consultants, and commercial firms, as well as the technology transfer offices of research organisations. To reach farmers and growers, for example, technology transfer can involve working with farmers one-on-one, presenting to groups or being involved in large community events such as field days. However, surveys show technology transfer support for farmers and growers is fragmented, thinly spread and insufficient.[603] More connectivity between groups, or the development of a more formal system to aid technology transfer in the food system, could support better uptake of technology.

… surveys show technology transfer support for farmers and growers is fragmented, thinly spread and insufficient.

7.2 Supporting research and innovation to prevent food loss and waste

Within the primary industry sector in particular, Aotearoa has shown it can quickly adopt new innovations and technologies. New Zealand is well placed to lead the way in sustainable development and FLW reduction goals, but this is not a research agenda that has been prioritised.

There is also a pressing need to develop the systems and processes to generate and collate data, to be able to share evidence around FLW and practices that prevent FLW. The New Zealand Research Information System, developed by MBIE, has already begun databases of research projects focused on managing extreme weather, and COVID-19, and could potentially collate data on FLW projects.[604]

There is also a pressing need to develop the systems and processes to generate and collate data, to be able to share evidence around FLW and practices that prevent FLW.

Collaborative partnerships between public and private sectors or internationally could benefit research and innovation in FLW.[*,605-609] For example, the UoO has a research project funded through the Climate Emergency Response Fund as one of MfE's national food waste reduction programmes, which brings together a consortium of organisations in the retirement housing sector, including Arvida, Bupa, and the Retirement Villages Association. The project aims to measure and reduce the amount of food waste in commercial kitchens in the sector.[569] Research in agricultural and environmental sustainability can also benefit from international research collaborations. For example, INRAE – France's research organisation for agriculture and the environment – and Science New Zealand have an agreement for researcher exchange programmes and collaborative projects including quality food products, carbon neutral and climate resilient agri-food, and the circular bioeconomy.[610] New Zealand's strength in agricultural and food research is internationally recognised and attractive to potential collaborators.

International private collaborations can also benefit New Zealand's food ecosystem. A new raspberry breed with early maturing has been developed by Plant & Food Research and Northwest Plant Company from Washington in the US, which extends the harvest window and is machine

[*] For example, Plant & Food Research and Zespri funded a 50/50 joint venture Kiwifruit Breeding Centre, which commenced operating from October 2021 to create new cultivars such as RubyRed™ Kiwifruit. Zespri also co-funded research with Kiwifruit Vine Health (known as KVH) to minimise impacts of the bacterium *Pseudomonas syringae pv. Actinidiae* (psa-*V*) infection on Kiwifruit and support growers with detection, management and technology transfer. Also, Zespri provides a $2 million innovation fund with key areas including waste management, sustainable packaging, technologies for growers to reduce carbon footprint and increase efficiency of yield.

harvestable, as well as meeting the requirements of processors.[611] Rabobank also carries out and collaborates on food and agribusiness market research, including a recent collaboration with KiwiHarvest investigating food waste at the consumer level.[612,613]

Understanding and addressing the issue of FLW requires involvement from all levels of society. Citizen science approaches have been used to investigate various aspects of the food system, including FLW, internationally.[614-616] Partnerships between industry and academia may be well placed to capitalise on the opportunities presented by citizen science.

8. Preventing food loss and waste requires a systems approach

Economic incentives and supply chain power dynamics drive much food loss and waste

In our present food supply chains, the costs of FLW are accrued where the FLW is realised, not where it is caused. This increases the costs of doing business for our growers and other upstream actors, while providing no incentive for more powerful downstream actors not to order more than they will need. While there is an argument that loss occurring upstream has fewer environmental impacts than FLW occurring downstream,[136] interventions that shift waste from one part of the supply chain to another, but do not reduce the amount wasted, are ultimately not preventing FLW. Mechanisms such as innovative contracting arrangements and the newly implemented Grocery Supply Code could help in moving the economic costs of lost and wasted food to the part of the supply chain where it was caused.

A 'both, and' approach will get us further than 'either, or'

There is no single cause of FLW in our food system, and so it is unlikely that there will be a single solution. At the highest level, we should invest in technical and other solutions that optimise the operations of the supply chain, while also ensuring that the market is set up to incentivise prevention of FLW. Similarly, we can implement prevention measures simultaneously across the supply chain, rather than prioritising a single stage or intervention.

In isolation, some approaches to preventing FLW may be in tension with our wider sustainability goals. Packaging can preserve shelf life, but may create more plastic waste. We will need to take a whole-of-system approach to reconcile these types of tensions.

Technology won't save us, but it can help

Scientists, engineers, and entrepreneurs, both in Aotearoa and abroad, are innovating in ways that could prevent FLW. From breeding crops with characteristics that promote shelf life, to smart packaging that can help consumers, to digitalisation that can make supply chains more efficient, and many other advances, there are abundant opportunities in this space. With the right support for both the scientific and food systems, we can capture these opportunities.

However, some of the drivers of FLW are not amenable to technical improvements, but instead come from the structure of the market and the relationships between different actors across the supply chain. Consumer preferences and habits also play a role. These factors will need to be addressed alongside any gains we can make through scientific innovation.

Uncertainty doesn't have to be a barrier to action

Our prevention efforts are hampered by uncertainty. There are significant data gaps across the supply chain, and few mooted interventions across the supply chain have been rigorously evaluated. We can do better in this space, by developing our data collection, sharing, and storage capabilities and by advocating for evaluation as an integral part of intervention. This will stop uncertainty being a barrier to action in the long-term.

In the meantime, we can act despite uncertainty. We can triangulate information we do have about the operations of food supply chains in New Zealand and qualitative reports of drivers of FLW here with international data on FLW. We can experiment in our policy and practice where we have reason to believe action might prevent waste, and be rigorous in our evaluation of new policies, while being open to a possible need to change course when we have more information.

Annex 1: Loss and prevention in horticulture and arable production

There are many innovations that could reduce food loss in the horticultural and arable sectors. In this annex we survey some of the possibilities by sector.

Table 10: A non-exhaustive overview of technological solutions and management practices for food loss prevention in horticulture (apples, kiwifruit, stone fruit, grapes, and tomatoes) and arable (grain) production, including challenges to implementation and examples from New Zealand. Abbreviations: CODC = Central Otago District Council, e-Bins = electronic bins, FLW = food loss and waste, IoT = internet of things, t = tonnes, 1-MCP = 1-Methylcyclopropene, NZFN = New Zealand Food Network

Loss type and causes	Solution	Description	Challenges	Examples from NZ
Apple pre-harvest Losses in 2012 in the Central Otago region were estimated at 2,669 t of apples.[213] Causes of pre-harvest losses were largely attributed to an export focus meaning it was un-profitable to harvest some fruit that didn't meet specifications.[213] Pre-harvest losses of apples are also caused by labour shortages, and disease/rots.[213,131]	Automated harvesting and precision agriculture.	Replacing some of the need for manual harvesting through adopting automated harvesting applications would enable greater efficiency and reduce labour shortage issues.[617]	Automated harvesters require a large upfront cost so adoption by growers is currently low.[618]	Automated harvesters by Abundant Robotics are being used in the Hawke's Bay area to harvest apples.[619]
	Genetic engineering.	Genetically engineered apple varieties can reduce the impact of severe weather events making them stress tolerant and less likely to fail to meet quality specifications. Artic apples are a good example, as they don't brown easily when bruised, allowing for fewer rejections.[620]	Genetic engineering has had limited commercial success in horticultural crops to date. The commercial release of genetically modified, and especially transgenic, crops also has many regulatory challenges.[224]	No specific data identified.
	Gleaning.	Farmers could implement gleaning in their apple orchards by enabling gleaning organisations access to pick any remaining apples post-harvest.[621]	Gleaning has many liability concerns which can affect farmer willingness to implement this strategy.[621] The *NZ Food Act 2014* protects donors from civil and criminal liability that results from consumption of food donated by the donor, as long as a few requirements are met.[112,622]	Perfectly Imperfect is an example of a company exercising gleaning to rescue food loss on farm in NZ.[28]
	In-field sorting.	Utilising an in-field sorting machine is a way growers can reduce the cost of post-harvest handling, making harvesting more of the apple crop economically viable.[618]	No specific data identified.	No specific data identified.
	Protective netting.	Protective netting in orchards has a range of benefits for reducing fruit loss. They protect against intense sunlight and extreme weather events like hail	No specific data identified.	Protective netting is widely used for orchards across NZ. Companies offering netting products and services include NZ Canopies,[623] AGROW plastics,[623] etc.

Loss type and causes	Solution	Description	Challenges	Examples from NZ
		and strong winds and provide a physical barrier against pests.[138]		
Apple post-harvest Losses in the Central Otago region. The CODC estimated 124 t of apples were lost in 2021 after being harvested.[213] Losses are caused by fruit deterioration during transport such as firmness loss, decay, internal disorders such as scab, and bruising.[624]	Automated harvesting.	Automated harvesting applications minimise bruising and the picking of unripe fruit, reducing FLW.[617]	No specific data identified.	No specific data identified.
	Donations.	Donations give a destination for food not consumed or sold and help minimise food loss.[625]	No specific data identified.	No specific data identified.
	Edible coatings.	Edible coatings can be applied and improve the shelf life of apples minimising post-harvest food loss.[626]	No specific data identified.	No specific data identified.
	Good harvest practices.	Quality issues can be greatly reduced in the apple industry when good harvest practices are employed:[624] for example, avoiding harvesting fruit during wet weather, using padded buckets, gentle filling of bins, opting for air suspension in transport vehicles, choosing the smoothest road to the packhouse, training pickers to minimise damage, strategically placing waste bins for unwanted fruit, avoiding direct sunlight on harvested fruit with bin covers.	No specific data identified.	Hazel Technologies[627] works within the NZ horticultural sector across a range of produce to deploy innovations to extend and optimise shelf life and quality of produce, for example from the apple industry.
	In-field sorting.	In-field sorting integrated with harvest assist platforms can be used to minimise losses in post-harvest storage by avoiding contamination of diseased fruit with healthy fruit and allowing gentle filling of buckets, reducing post-harvest loss.[628]	Currently there is minimal in-field sorting technology available to growers and upfront cost is high, which means adoption by growers is low.[618]	No specific data identified.
	IoT.	IoT can provide pest and disease information to farmers so they can quickly control them.[629]	No specific data identified.	No specific data identified.
	Protected cultivation.	Protected cultivation by way of nets, foil, or glass means fruit is less affected by weather conditions and pests, which reduces food losses.[630]	Upfront investment costs of netting solutions are high making them unviable for some growers.[624] For example, some growers have high operating costs due to needing to purchase costly licences to grow the fruit in NZ. Therefore, many	GROWTECH group is developing specific hail and wind resistant nets for the kiwifruit industry.[631]

Loss type and causes	Solution	Description	Challenges	Examples from NZ
			orchards opt to not cover their crops with netting solutions.[631]	
	Training of staff.	Training of staff to focus on gentle techniques for handling fruit when harvesting can greatly reduce rejections due to quality issues associated with bruising and cuts on the fruit.[630]	Training staff can be challenging; for example, many horticultural workers come from overseas and so there may be a language barrier.	No specific data identified
Kiwifruit pre-harvest Losses (no specific data identified). Caused by labour shortages, low market price, overproduction, pests, birds, and weather.[48]	E-bins.	E-bins help open up kiwifruit picking jobs to a wider range of people as it reduces the need for pickers to carry around a bucket, which can be physically straining.[228]	Automated harvesters require a large upfront cost so adoption by growers is low. Many mechanical harvesters also require orchards to alter the shape of the apple tree.[617] Variation of crops and environment makes automated harvesters difficult to make commercially available.[617]	The electronic e-Bin was developed at University of Waikato in collaboration with Zespri to combat the labour shortage issue and is reported to be implemented in the 2023/2024 season.[228]
	Gleaning.	Farmers could give access for gleaning services in their apple orchards to rescue produce that was not harvested.[621]	Gleaning has many liability concerns which can affect farmer willingness to implement this strategy.[621] The *NZ Food Act 2014* protects donors from civil and criminal liability that results from consumption of food donated by the donor, as long as a few requirements are met.[112,622]	Perfectly Imperfect is an example of a company exercising gleaning to rescue food loss on farm in NZ.[28]
Kiwifruit post-harvest The kiwifruit industry reports an estimated 38,000-40,000 t of post-harvest food loss per year, amounting to approximately 8% of the total yield in NZ.[47] Losses caused by pre-mature harvesting, improper handling, mould, perishability, or loss of firmness during storage causing rejection.[48]	Donations.	Donations give a destination for food not consumed or sold and help minimise food loss by giving to those in need.[625]	No specific data identified.	A Tasman grower donated 35 T of damaged kiwifruit to NZFN's distribution hub in late 2020.[632]
	Training of staff.	Training of staff to focus on gentle handling of fruit when harvesting can greatly reduce rejections due to quality issues stemming from bruising and cuts on the fruit.[630]	Training staff can be challenging; for example, many horticultural workers come from overseas and so there may be a language barrier.	No specific data identified.
	Treatments.	Calcium treatments have success at improving the storage of kiwifruit to maintain their firmness levels for longer.[633] 1-MCP treatments and melatonin have been successful at delaying ripening, reducing weight loss, and maintaining fruit firmness.[634]	No specific data identified.	Hazel Technologies is a company that works with NZ kiwifruit growers to provide solutions to extend shelf life, reduce rejections, and combat food loss. They have developed a sachet containing 1-MCP to extend post-harvest shelf life.[627]

Loss type and causes	Solution	Description	Challenges	Examples from NZ
Stone fruit pre-harvest In 2021 volumes of loss due to non-harvested fruit in Central Otago were estimated to be 1,086 t (9%) of cherries, 163 t (7%) of apricots, 233 t (4%) of peach/nectarines.[213] Losses were caused by labour shortage, low market price, overproduction, pests, birds, and weather.[213]	Gleaning.	Farmers could give access for gleaning services in their orchard to rescue the remaining produce post-harvest.[621]	Gleaning has many liability concerns which can affect farmer willingness to implement this strategy.[621] The *NZ Food Act 2014* protects donors from civil and criminal liability that results from consumption of food donated by the donor, as long as a few requirements are met.[112,622]	Perfectly Imperfect is an example of a company excising gleaning to rescue food loss on farm in NZ.[28]
	IoT.	IoT has the ability to provide real time data for the orchard environment which can assist in early pest detection, maturity assessment and temperature control which can help the farmer make decisions to ensure quality of fruit. Examples include frost alarms and early pest detection systems.[635]	Farmers and agricultural companies tend to only adopt new technologies based on financial assessment, which is hard to demonstrate until the technology has been adopted.[636]	Harvest is a NZ company which integrates IoT into their monitoring systems.[637]
	Protective covers.	Installing covers allows protecting against weather events, pests, and can also improve ripening.[636]	Installation of covers requires a large initial investment and also has reoccurring costs due to maintenance.[625]	No specific data identified.
Stone fruit post-harvest In 2021 volumes of harvested food loss in Central Otago were estimated at 1,121 t (9%) of cherries, 76 t (3%) of apricots, and 693 t (12%) of peach/nectarines. Harvested fruit losses were caused when harvesting the fruit was not economically viable, and/or the weather conditions impacted the achievement of cosmetic specifications.[213]	Treatments.	1-MCP treatments can extend shelf life in stone fruit.[627]	No specific data identified.	No specific data identified.
	Value-add products.	Value-add products are a way to manage waste and give a premium to the farmer. Stone fruit have a variety of beneficial properties and have many valorisation options.[638]	Usually, some infrastructure required to make a value-add product which could be costly in the beginning for the farmer.	Eden's Orchards New Zealand makes a wide range of juices from imperfect fruit including cherry juice. They are also trialling freezing of processing grade cherries preventing them from going to waste.[639]

Loss type and causes	Solution	Description	Challenges	Examples from NZ
Grape pre-harvest Loss (no specific data identified). Main causes of loss labour shortages, low market price, overproduction, pests, birds, weather.[48]	Gleaning.	Grape growers could implement gleaning onto their vineyards which can rescue produce that has not been harvested by allowing volunteers and initiatives to pick remaining grapes post-harvest.[621]	Gleaning has many liability concerns which can affect farmer willingness to implement this strategy.[621] The *NZ Food Act 2014* protects donors from civil and criminal liability that results from consumption of food donated by the donor, as long as a few requirements are met.[112,622]	Perfectly Imperfect is an example of a company excising gleaning to rescue food loss on farm in NZ.[28]
	Mechanised harvesters.	Mechanised harvesters could be implemented to solve the issue of labour shortages in vineyards and reduce losses.[640]	Mechanised harvesting equipment can end up been more expensive than hiring workers and could cause the price of grapes to increase.[640]	No specific data identified.
	Precision agriculture.	Precision agriculture has a place in viticulture and has the ability to reduce risk of crop loss, disease incidence, labour costs and time management.[641]	No specific data identified.	Croptide has developed a novel sensor which allows growers to read the plant status directly from stem.[642]
	Waste reduction programmes.	NZ Wine reports that 98% of wineries in NZ have waste reductions programmes in place and 75% of wineries have reduction initiatives. They have also set a target for the NZ wine industry to achieve zero waste by 2050.[643]	No specific data identified.	No specific data identified, but see *Beyond the bin: Capturing value for food loss and waste* for ways that grape marc is being used.
Grape post-harvest No specific data identified.	Donations.	Donations give a destination for food not consumed or sold and help minimise food loss.[625]	No specific data identified.	No specific data identified.
	Treatments.	Ozone treatments have been shown to reduce decay of cold store grapes and are effective for controlling post-harvest losses.[644]	No specific data identified.	Hazel Technologies works with grape growers and has 1-MCP treatments that can extend shelf life. They have also developed a mat that absorbs excess moisture reducing risk of fungal infection.[627]

Loss type and causes	Solution	Description	Challenges	Examples from NZ
Tomato production pre-harvest One report estimates between 71% and 84% of produced tomatoes were left in the field and not harvested by two commercial growers in Australia.[41] The main causes of loss include labour shortages, low market price, overproduction, pests, birds, weather.[48]	Gleaning.	Farmers could implement gleaning onto their orchard which can rescue produce that has not been harvested by allowing volunteers and initiatives to pick remaining produce post-harvest.[621]	Gleaning has many liability concerns which can affect farmer willingness to implement this strategy.[621] The *NZ Food Act 2014* protects donors from civil and criminal liability that results from consumption of food donated by the donor, as long as a few requirements are met.[112,622]	Perfectly Imperfect is an example of a company excising gleaning to rescue food loss on farm in NZ.[28]
Tomato post-harvest Estimated post-harvest loss for two commercial tomato growers in Australia was found to be between 40.3% (55.34 t) and 55.9% (29.61 t) of the total harvestable product. It was determined that between 68.6% and 86.7% of undamaged, edible, harvested tomatoes were rejected as out grades and consequently discarded due to product specifications.[645]	Donations.	Donations give a destination for food not consumed or sold and help minimise food loss by giving to those in need.[625]	No specific data identified.	No specific data identified.
	Evaporative cooling.	Evaporative cooling has been shown to be effective at increasing shelf life in tomatoes.[646]	No specific data identified.	Hazel Technologies works with tomato growers and has 1-MCP treatments that can extend the storage potential of tomatoes.[627]
Grain/arable No specific data identified.	Cameras.	Farm Wave has developed a camera that attaches to harvesters and lets the farmer know how much grain is left behind during harvest so they can make adjustments to reduce waste.[227]	No specific data identified.	No specific data identified.
	Integrated crop management.	Pests and diseases are the main reason for losses in grain production. Integrated crop management is a way to reduce losses. An example of this is introducing natural predators as a way to control pests.[647]	No specific data identified.	No specific data identified.

Annex 2: International examples of organic bans to landfill

An increasingly common approach to FLW prevention is the implementation of landfill bans to incentivise other uses of surplus food further up the FLW hierarchy (see figure 1). A scan of international policy settings indicates a variation in ways that bans have been implemented, interpreted, and enforced. Since waste is generally managed locally across jurisdictions, there are cases where organics bans to landfills are in place in particular locations, but not country-wide (see table 11, table 12, table 13, and table 14). Some local authorities have enforced recycling laws or bans based on the availability of landfills, increasing costs of moving solid waste to other areas, or legislative requirements (for example, directives from the EU).

Food may not be the primary organic material targeted, and therefore the broader classification of 'organic' bans has been used here. Other classifications include compostable, biodegradable, or biological waste. Depending on the municipal solid waste (MSW) management plans, the extent of the ban may be also dependent on who the generator of FLW is. For example, regulations may only be applicable to those that produce over a certain quantity of FLW per week.

The examples below include – a range of organic bans implemented with the aim of reducing the total volume of organic material in landfills. Details across jurisdiction vary, with different rules applying to processed organic material, such as anaerobic digestate. Additionally, recycling laws that mandate source separation are not included.

The information in table 11, table 12, table 13, and table 14 includes examples of organic bans in different contexts (tables are grouped by continent; examples within tables are alphabetically ordered by country), summarising the scope and outcomes of organics bans, as well as additional information regarding their implementation. These tables are included to illustrate the range of policies internationally but are not comprehensive.

Africa

Table 11: Example of organic waste ban from South Africa. South Africa does not have any country-wide organics ban to landfill, however the Western Cape province has enforced a ban and set targets. Abbreviations: FLW = food loss and waste, t = tonnes.

Location	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of waste	Additional notes
Western Cape	*National Environmental Management: Waste Act*, 2008 (Act No. 59 of 2008). National norms and standards for disposal of waste to landfill (*GN No. R. 636 of 2013*).	2022 for 50% reduction, 2027 for 100% reduction.[648]	All organic waste from households, factories, businesses, and restaurants.[649]	No detail for FLW, but refers to abattoir waste, green waste, and liquid waste.[649]	More than 600,000 t of organic waste diverted from landfill.[649]	Ban requires to divert up to 50% of all organic waste from landfilling, with the aim to increase this to 100% by 2027.[648,650]

Asia

Table 12: Examples of organic waste bans from Indonesia and South Korea. Indonesia does not have a country-wide organics ban to landfill, however West Java province does have an enforced ban. South Korea has a country-wide ban specifically for sending FLW to landfills. Abbreviations: FLW = food loss and waste, t = tonnes.

Location	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Indonesia: West Java	*02 /PBLS.04/DLH*[651]	2024[651]	All organic waste, no specific groups.	Includes FLW.[652]	No data available.	The Sarimukti landfill fire in 2023 has resulted in the ban of organic waste from Bandung City, Cimahi City, Bandung Regency, and West Bandung Regency by the Governor of West Java.[652] The ban has been enforced since 1 January 2024.

Location	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
South Korea	*Waste Management Act*: prohibition of direct landfilling of FLW.[653]	2005[653]	All FLW generated by agriculture, fisheries, leftovers from production, distribution, and cooking.[653]	FLW going to landfill is limited to residues and contaminants from treatment facilities.[654]	Food waste generation from homes and restaurants had increased from about 13,500 t per day to about 15,500 t per day (14.5%) between 2010-2020.[655]	The prohibition of FLW to landfill did not lessen the amount of FLW generated, but rather enforced other government supported/funded options for waste diversion. Several other policies and legal instruments support the diversion of FLW from landfills.[654] In 2013 a weight-based food waste fee for consumers to use food diversion services was extended. The volume-based waste free system charges consumers based on the weight of their FLW.[656] Individuals reduce weight by removing excess water content from their food.[564]

North America

Table 13: Examples of organics waste bans in North America. Canada does not have any nationwide organics ban; however, Nova Scotia (province) and Vancouver (city) have enacted policies. The US do not have a country-wide ban; however, a number of states and smaller territories have taken the additional step of banning FLW at various levels and generators. Abbreviations: CMR = Code of Massachusetts Regulations, FLW = food loss and waste, MSW = municipal solid waste, t = tonnes.

Location	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Canada: Nova Scotia (Province)	*Solid Waste-Resource Management Regulations*, enabled under the *Nova Scotia Environment Act*.[657]	1998[657]	All compostable organic material from industrial, commercial, institutional, and residential sources.[657]	FLW and other organic material to be composted.[657]	No current diversion data readily available.	In addition to the landfill ban, Nova Scotia has promoted its bans through education (to establish waste-separation standards) and funds a third party to deliver.[658]
Canada: Vancouver (City)	*Solid Waste By-Law No. 8417*.[659]	2015	All organic material, including food scraps.[659]	All FLW, residential and non-residential.[659]	In 2021, more than 400,000 t of yard and FLW have been diverted from landfill.[660]	Owners and occupiers of non-residential properties producing FLW (or organic waste) must have a diversion plan for FLW.[659] Waste is inspected when it is delivered to a regional disposal facility, where excessive amounts of food results in the hauler paying a 50% surcharge on the cost of disposal.

Location	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
US: Massachusetts (State)	*310 CMR 19.000: Solid Waste Facility Regulations.*[661]	First implemented in 2014, lowered limits in 2022.[661]	Commercial food/organic wastes from facilities generating 0.5 t of waste per week.[661]	Food/organic waste may be donated, turned to animal feed, composted, or anaerobically digested.[662]	Prior to the lowered 2022 limit, Massachusetts had already diverted 360,000 t of FLW in 2022.[662]	Food/organic waste is banned from disposal or transport for disposal.[661] This is part of a wider Massachusetts Department of Environmental Protection's goals to reduce waste by 30%.[663] This ban is not specifically for landfills, as Massachusetts also incinerates and transfers waste out-of-state. There is a local food action plan to support FLW reduction and rescue. FLW reduction is actively tracked in businesses and institutions.[662]
US: Seattle (City)	*Seattle Municipal Code 21.36.082–21.36.083.*[664]	2015[664]	All households and businesses.[664]	FLW and other recyclables must not be disposed as MSW.[664]	Even though Seattle's population has increased by 35% between 2000 – 2020, commercial and residential waste trends are promising. Residential data shows the amount of waste generated per person per day decreased by 16% (apart from COVID-19 time periods).[665]	Households are liable to pay a $50 fine, and businesses may need to pay a fee if more than 10% of waste contains prohibited material, including FLW.[664] Food and yard waste services must be subscribed to, with monthly costs relating to the size of the cart.[666]
US: Vermont (State)	*Universal Recycling Law* (Act 148).[667]	2020[667]	All households, businesses, and institutions.[667]	All FLW; pre- and post-consumer.[668]	Estimates place organic waste diversion at nearly 70,000 t in 2020. Additionally, more than 4,000 t of food were also rescued.[668]	General recycling law was passed in 2012 and implemented in stages to reduce landfill disposal.[668] Residents may dispose of meat and bones in residual waste if they compost at home. Businesses may dispose of small amounts of FLW, especially in packages that are too small for de-packaging machines.[667]

Europe

Table 14: Examples of organic bans to landfills across Europe. Included here are examples from across the EU, Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Lithuania, Luxembourg, Netherlands, Norway, Poland, Slovenia, Sweden, Switzerland, and Scotland. Abbreviations: BMW = Biological municipal waste, FLW = food loss and waste, kg = kilogram, m = million, MBT = mechanical-biological treatment, MJ = megajoules, MSW = municipal solid waste, Mt = megatonne, PAYT = pay as you throw, t = tonnes, TOC = total organic carbon.

Location	Ban status	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
EU Member States (27+)	No ban, targeted reduction	Landfill directive 1999/31/EC *European waste framework directive 2008/98/EC* *European new waste framework directive 2018/851*	1999	All EU member states are to reduce the amount of biodegradable MSW sent to landfill.	Obligations include preparing FLW prevention programmes, implementing related actions, monitoring, and reporting on progress achieved at various supply chain levels.[669,669]	A 2020 report stated that diversion of FLW was more than 9.5 Mt per year in the EU.[670]	An amendment passed in March 2024, raised legally binding FLW reduction targets to 40% for the consumption level (retail, distribution, restaurants, and food services as well as households) and to 20% for food processing and manufacturing by 31 December 2030.[345]
Austria	Ban	Landfill Ordinance Law Gazette II No. 164/1996.[671]	2004	MSW with TOC content >5% is banned. There are exceptions for MBT treated waste.[671]	There is no specific FLW regulation.	Austria achieved almost 0% BMW landfilled by 2006.[671]	In addition to the landfill ban, Austria uses a landfill tax, incineration tax, producer responsibility measures, PAYT and mandatory separate collection systems to decrease the incentive for landfilling organic waste.[672]
Belgium	Ban only in states of Flanders and Wallonia.	VLAREMA- Flemish *Regulation on Sustainable Materials Management and Waste*.[673] Walloon Waste-Resources Plan.[674]	2007	All biodegradable waste streams.[675]	Wallonia – Management of FLW using ladder (hierarchy) model, with specific prevention measures.[674] Brussels Capital Region does not have landfills.	The reported rate of landfilled biodegradable municipal waste has been reported as 0% in 2017, 2018, and 2019.[675]	The landfill ban added to the existing landfill tax in Flanders and Wallonia, there is also an incineration tax in all three regions of Belgium encouraging a waste hierarchy.[675]

Location	Ban status	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Czech Republic	Aiming for a ban in the future	*Act no. 541/2020 Coll. on Waste* (Waste Act)[676]	2020	All MSW.[676]	There are plans to expand the separate collection of FLW.[676]	The Czech Republic generated about 1.5 Mt of BMW in 1995. The amount of biodegradable MSW landfilled in 2020 was 28.3% of the reference value in 1995.[676]	Currently policy instruments include PAYT, a landfill ban for separately collected waste streams suitable for re-use or recycling and a landfill tax. The landfill tax will gradually increase, and a landfill ban for recyclable, recoverable and mixed MSW (including dry matter with a calorific value of 6.5 MJ/kg) from 2030 onwards will be introduced.[676]
Denmark	Ban	*Environmental Protection Act* and the *Statutory Order on Waste*.[677]	1997	All organic and combustible MSW.[678]	The separate collection of FLW is not covered by all municipalities (56%).[677]	The landfilling rate of Denmark in 2020 was slightly below 1% of the BMW generated in 1995, and for many years has been 1%-2%.[677]	Denmark has had a landfill tax in place since 1987. As of 2023, non-household waste generators will be obliged to sort their waste for separate collection.[677]
Estonia	Partial ban	Regulation of the Ministry of the Environment 29.04.2004, No 38 (RTL 2004, 56, 938).[679]	2008	All untreated and unsorted waste. The share of biodegradable waste in MSW landfilled cannot exceed 20% by weight.[680]	The Estonian Waste Act aims for door-to-door collection of bio-waste, or home composting to become mandatory for all residents by the 31st December 2023.[680]	Estonia landfilled 9% (29,071 t) of biodegradable MSW in 2019 as proportion of the BMW reported in 1995 (317,000 t).[680]	The limit to biodegradable content in landfilled MSW gradually decreased from 45% in 2010, 30% in 2013 and 20% in 2020. Other fiscal policies include a landfill tax, municipal waste user charge, PAYT, packaging tax, penalties, and fines.[679]
Finland	Ban	*Government Decree on Landfills 331/2013* – Prohibiting landfill of organic waste.[681]	2016	All organic and biodegradable MSW with TOC >10%.[682]	If TOC >10%, FLW included in ban (no specific FLW regulation).	Finland landfilled 3% BMW in 2016, and 1% for 2017, 2018, and 2019, of the total amount of BMW produced in 1995.[682]	Statistics suggest that the most significant reduction in landfilling between recorded 1997 and 2016 is from landfill tax.[681]
France	Ban	*Code de l'environnement Loi No 92-646, 1992*.[344]	2002	All untreated MSW.	Separate bio-waste collection will become mandatory by 2025.[344]	France reported 15% biodegradable waste being landfilled for 2016 of the total amount BMW produced in 1995.[344]	Landfill tax differs by classification, and there are plans to increase its landfill tax by 2025.[344]

Location	Ban status	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Germany	Ban	Landfill ordinance.[683]	2005	Waste with a TOC >3% (18% for mechanical-biologically treated waste) is banned.[683]	Separate bio-waste collection was made mandatory from 2015.[683]	Germany achieved 0% BMW landfilled in 2016.[683]	In addition to the landfill ban, Germany uses PAYT and mandatory separate collection systems to decrease the incentive for landfilling.[683]
Hungary	Partial ban	*Decree No. 385 of 2014 (XII. 31.)* Korm of the Government concerning the conditions of providing waste management public service.[684]	2003	All untreated MSW is banned since 2002, a partial ban on organic wastes since 2003.[684]	No specific FLW regulation.	Hungary reported 28% biodegradable waste landfilled in 2019, as a percentage of the total amount of biodegradable MSW produced in 1995.[684]	Hungary also has a landfill tax and PAYT scheme implemented in over 80% of the country.[684]
Lithuania	Ban	Law on Waste Management *(No. VIII-787).*[685]	2003	All untreated MSW and all biodegradable waste from gardens, parks, and green areas.[686]	No specific FLW regulation.	Lithuania reported 3% BMW landfilled in 2019, as a percentage of the total amount reported in 1995.[686]	In addition to the landfill ban, Lithuania uses a landfill tax, producer responsibility measures, PAYT and some mandatory separate collection systems to decrease the incentive for landfilling organic waste.[686]
Luxembourg	Ban	Specific policy name not found.	Specific year not found.	Ban on untreated MSW and organic waste (TOC > 5%).[686]	No specific FLW regulation.	Luxembourg reported 5% BMW was landfilled in 2016 as a percentage of the total amount reported in 1995.[686]	Door-to-door separate collection is the main system in cities, towns and suburbs, and rural areas for bio-waste. Bio-waste is also collected at civic amenity sites.[686]
Netherlands	Ban	Decree on Landfill and Waste Disposal Bans *(Besluit stortplaatsen en stortverboden afvalstoffen)*[687]	1995	Mixed MSW is banned. 35 waste streams are captured, including all combustible and biodegradable waste, with TOC >5%.[688]	No specific FLW regulation.	Netherlands reported 2% BMW landfilled in 2016, as a percentage of the amount in 1995.[688]	There is also a Landfill Tax (1995), which has been marginally increasing since its implementation. Since 2018, there are over 60 waste streams captured in the landfill ban.[688]

Location	Ban status	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Norway	Ban	*Waste Regulations* (2004) – Chapter 9, Landfill bans for waste types (includes landfill ban on biodegradable waste – introduced 2009).[681]	2009	All biodegradable waste streams with a TOC >10% or organic matter >20%.[689]	Up to 70% of municipalities offer separate door-to-door collection of bio-waste.[681]	Landfilling decreased from 25% of MSW in 2001 to 6% in 2010.[689]	The landfill ban joined the existing policy initiatives, Landfill Tax (1999) and Incineration Tax (1999).[681]
Poland	Ban	*Specific policy name not found.*	2013	All biodegradable waste collected separately (2013). All combustible waste with >5 % TOC, >8% LOI, Calorific value > 6MJ/kg (2016).[690]	Door-to-door separate collection of biodegradable waste is mandatory.[690]	Poland reported 13% BMW landfilled in 2016 and 11% in 2018, as a % of the total amount in 1995.[690]	Poland has a PAYT system, but it is targeted only for non-household waste producers.[690]
Slovenia	Ban	Decree on waste to landfill (Official Gazette of the Republic of Slovenia, no. 10/2014 and 54/15).[691]	2011	All BMW streams based on calorific content and TOC.[690] *(No mention of limits for calorific content and TOC found)*	No specific FLW regulation.	Slovenia reported 15% BMW landfilled in 2019 (four-year derogation period), as a percentage of the generated amount in 1995.[690]	Slovenia has a landfill tax and PAYT system based on waste container volume and the frequency of collection.[690]
Sweden	Ban	Ordinance (2001:512) on the disposal of *waste Sveriges riksdag, 2001, Förordning (2001:512) om deponering av avfall (SFS).*[692] As of 2024, a new Swedish law declares that everyone must separate their FLW.[693]	2005[694]	All organic and combustible waste streams.[695]	The Swedish government has set targets for FLW such as by 2018, at least 50% of food waste from households, commercial kitchens, shops and restaurants will be sorted out and treated biologically,[696] and to decrease by 20% weight per person from 2020 to 2025.	Over the past five years, the overall landfilling rate in Sweden is less than 1% and reported zero biodegradable waste landfilled in 2018.[695]	In addition to the landfill ban, Sweden uses a landfill tax, producer responsibility obligations and PAYT to decrease the incentive for landfilling organic waste.[695]
Switzerland	Ban	*Ordinance on the avoidance and the disposal of waste.*[697]	2000[698]	All combustible, including biodegradable waste streams.[698]	No specific FLW regulation.[698]	No BMW has been landfilled in the country since 2006.[698]	A level of zero BMW landfilling has been achieved by the combination of incineration and recycling.[698]

Location	Ban status	Policy instrument(s)	Year enacted	Scope	FLW specifics	Diversion results of organic waste	Additional notes
Scotland	Aiming for a ban in the future	*Landfill (Scotland) Regulations 2003*, Regulation 11(3).[699]	2025[699]	All BMW streams with a TOC >5%.[699]	FLW included in ban (no specific FLW regulation).[700]	No data.	Ban was initially planned to be enforced in 2021 but has since been pushed back to December 2025.[701,702]

Annex 3: Interventions to prevent food waste in retail and food service

Interventions to prevent food waste in RFS are wide-ranging, reflecting the diversity of causes of food waste in these sectors, as well as an array of sector specific challenges in managing flows of food. In this annex, we highlight commonly cited interventions designed to reduce food waste in RFS settings, as derived from ReFED's Solution's Database[424] and MfE's literature review[394] of organic waste reduction initiatives in households and businesses. For clarity, we have grouped interventions into four general categories: 1) sales strategies, 2) solutions specific to food service, 3) transport, logistics, and inventory management, and 4) waste measurement and tracking. It is worth noting that much of the evidence around these interventions is not specific to New Zealand, so care would need to be taken when applying interventions to the New Zealand context to achieve effective implementation.

Table 15: An overview of interventions to prevent food waste in the RFS sectors, the type of waste they address, how they're used, and available evidence around their effectiveness in reducing food waste. Interventions are grouped by categories (sales strategies; solutions specific to food service; transport, logistics, and inventory management; and waste measurement and tracking). Abbreviations: 2D = two dimensional, EECP = European Cluster Collaboration Platform, EPA = Environmental Protection Agency, m = million, MfE = Ministry for the Environment, Mt= megatonne, RFS = retail and food service, t = tonnes.

Intervention	Type of waste	How it is used	Evidence of effectiveness
Sales strategies			
Assisted distressed sales.	Retail: spoilage waste.	The use of third party companies or apps to sell salvaged, out-of-spec, overstocked, or out-of-date (but safe) food at a discounted rate.[703] Examples of overstock food buyers in the US include Natural Choice Foods,[704] Marvell Foods,[705] and Mid-America Food Sales.[706] In NZ, companies like Surplus Direct[707] buy and sell a range of surplus stock, including some food products.	ReFED estimates that greater uptake of assisted distressed sales across US retailers could divert up to 306,000 t of food waste annually.[703] The scale of operations at US company Natural Choice Foods[704] is indicative of the potential for this intervention; the company handles about 200,000 cases of overstock food every week, and are connected to 1,000 secondary market outlet stores across 35 states. However, there is little to no scientific study evaluating the efficacy of this intervention. Self-reported data from markdown applications – a strategy for assisted distress sales (see below) – indicates that this intervention can have a significant impact on food waste.
Dynamic pricing.[708]	Retail: spoilage waste.	This automates the process of marking down products in-store, in particular to provide discounts on products near their expiration date.	Modelling suggests that dynamic pricing outperforms static pricing in reducing food waste and increasing profit for fresh produce retailers,[411] however, limited real-world study is available. ReFED estimates that implementation of dynamic pricing in the US retail sector could divert 352,000 t of food waste annually.[708] In Finnish retailers, early evidence indicates that end-of-day product markdowns can both reduce food waste and increase gross profit margins.[709] In Italy, a store introduced dynamic pricing technology by Wasteless,[710] and self-reported an in-store waste reduction in their fresh product categories of 39%. At Tesco, a large UK retailer, a dynamic pricing approach resulted in a 2% reduction in produce waste and annual saving of £30m.[711]

Intervention	Type of waste	How it is used	Evidence of effectiveness
Markdown alert applications.[712]	RFS: spoilage waste.	It lets consumers know that safe but short shelf life foods can be purchased at a discount. Examples include Too Good To Go, ResQ club[421] and Foodprint in Aotearoa.[420]	There is a shortage of independent, quantitative research on the efficacy of markdown applications, but self-reported data are encouraging. ReFED estimates that implementation of markdown apps in the US RFS sectors could divert 1 Mt of food annually.[712] According to their 2021 impact report,[713] Too Good To Go has saved over 52m meals since 2016, with a user base of 20m people and 82,000 stores across 17 countries. Marketing statistics from ResQ club (primarily in Finland) suggest that food service outlets can increase revenue by 2%-6% and sell half on of their surplus food.[421]
Specific to food service			
Doggy bags.	Food service: plate waste.	This allows customers to take food home with them.	Several studies indicate that doggy bags can be an effective tool for reducing plate waste.[714] For example, a Dutch study found that an opt-out strategy for doggy bags in food service settings increased doggy bag uptake to 74% of all leftovers (versus 27% for an opt-in approach).[715] However, their research suggests that an opt-out approach can have detrimental effects on restaurant or service staff evaluations, which may require changes to how doggy bags are presented to consumers. Given the scale of plate waste in NZ food service, an estimated 33% of food waste in the sector,[404] addressing doggy bag uptake is important. However, uptake of doggy bags can depend on cultural attitudes towards leftovers[716] and social stigma-related factions,[714] as well as how take aways are approached within the establishment.[715] For example, survey data from Italy suggests that just 30% of restaurant goers ask for the remainder of their food in a doggy bag, while 70% don't, citing reasons such as embarrassment or shyness (28%) or a lack of available containers (18%).[717] A Japanese study of attitudes towards doggy bags suggests that appealing more to customers concern for the environment by highlighting the sustainability benefits of using doggy bags would help uptake.[718] There is little specific data on how much food taken home in doggy bags actually gets eaten.
Challenges or competitions.	Food service: plate waste, preparation waste, spoilage waste.	Businesses can sign up to measure their waste and receive support to reduce it over time[394] (e.g. Nashville Mayor's Food Saver Challenge,[719] Denver's Food Waste Restaurant Challenge,[720] and the Worldchef's Food Waste Challenge).[721]	Challenges can be effective, but the evidence base for their long-term efficacy isn't as well developed as for other interventions.[394]
Menu planning.	Food service: plate waste, preparation waste, and spoilage waste.	Menu planning requires quantifying and measuring of food that is required or adjusting the menu for food not often sold.[722] Optimising the use of ingredients across multiple dishes, aligning with customer demands, and reducing surplus inventory.	Menu planning is a logical step in reducing food waste within food service, although there has been little scientific study linking the two specifically. To optimise menu planning, ReFED recommends that food service providers track waste operations (see row on waste tracking and measurement below).
Messaging for diners.	Food service: plate waste.	Includes initiatives like smaller plates at buffets, removal of dining trays at 'all-you-can-eat' diners, better menu descriptions, smaller portioning of side orders, etc.	As highlighted by an MfE review,[394] messaging interventions have been effective at reducing food waste in numerous food service environments, including university canteens, staff cafeterias, dining halls, buffets, and restaurants. For buffet style dining, ReFED estimates that buffet signage in 'all-you-can-eat' food service business in the US could divert up to 47,000 t of food waste annually.[723]

Intervention	Type of waste	How it is used	Evidence of effectiveness
Plate size, colour and shape.	Food service: plate waste.	Changing the size, colour, or shape of plates in food service settings can reduce over portioning by consumers.[724-726]	Changing the size and shape of plates is evidenced to reduce over portioning in university dining contexts. A US study found switching from a large round plate to a smaller oval plate reduced plate waste from 15.8% to 11.8%. A study of NZ tertiary institutions efforts to reduce food waste shows at least one university dining hall facility has reported successful food waste reduction from switching to smaller plates.[726] Additionally, a study of restaurants in China found the colour of the plate could also influence plate waste, noting that plate waste was reduced when the plate was a warm colour. It should be noted, however, this study does not distinguish whether this was a result of reducing over portioning or of over eating by consumers.[725]
Reduced portion sizes.[727]	Food service: plate waste.	Creating smaller size options on the menu can reduce over portioning.	Decreasing portion sizes can significantly reduce plate waste, as observed in several studies in a variety of food service settings.[728-732] While effective at preventing food waste, businesses may be reluctant to implement this measure, considering it a risk to their brand image.[727] ReFED estimates that reduced portion sizes across US food service business could divert up to 2.4 Mt of food waste annually.[727] In the context of buffet style venues, ReFED estimates that using smaller plates to reduce portion sizes could divert up to 47,000 Mt of food waste in the US annually.[733]
Trayless dining facilities.	Food service: plate waste.	Removing trays from 'all-you-can-eat' dining facilities to reduce over portioning by consumers.[734]	There is mixed evidence on the efficacy of going trayless, with most studies focusing on this intervention in university cafeteria settings. Several studies indicate that going trayless in cafeterias can reduce food waste,[724,735,736] although this isn't always the case[737] and outcomes can vary by food type.[738] ReFED estimates that going trayless in 'all-you-can-eat' food service businesses in the US could divert up to 99,000 t of food waste annually.[734]
Transport, logistics, and inventory management			
Decreased minimum order quantity.	Retail: spoilage waste.	Many retailers and food service businesses have minimum order quantities built into their ordering and replenishment systems to streamline operations, but this can result in sending slightly more food than meets demand to every location.[428] Trimming order sizes can help avoid overbuying and subsequent wastage.[428] This is particularly relevant for highly perishable products like meat, fresh produce, and seafood.	ReFED estimates that decreases in minimum order sizes across US retailers could divert 120,000 t of food waste annually.[428] However, there is little to no scientific study evaluating the efficacy of this intervention, nor available real-world data.

Intervention	Type of waste	How it is used	Evidence of effectiveness
Enhanced demand planning.[391]	RFS: spoilage waste.	This applies advanced forecasting and planning methods (e.g. machine learning software systems like Afresh[739]) to accurately predict consumer demand for products and efficiently manage inventory levels. This approach can integrate various data sources, such as historical sales data, current market trends, promotional calendars, and even weather forecasts, to create a more accurate and dynamic forecast of product demand.[422]	This is viewed as a key approach to reduce food waste in the RFS sectors,[444] although there is limited independent research quantifying its impact. ReFED estimates that implementation of dynamic forecasting in the US retail sector could divert 258,000 t of food waste annually.[391] Modelling from the Netherlands[740] suggests that dynamic forecasting performance varies greatly across products and scenarios, but consistently outperforms 'naïve' forecasting (where the forecast equals sales from the last period) in reducing food waste. Financially, this can have a notable real-world benefits; a decade of improvements to Tesco's dynamic forecasting system have saved the company a reported £100m a year.[741]
Improved storage conditions.	RFS: spoilage waste.	This ensures better ventilated warehouses and increased cold storage capacity.	ReFED estimates that improved temperature monitoring for food service in the US has the potential to divert 742 t of food waste.[742] A Swedish study focused on cheese, dairy, deli, and meat products found that a reduction of supermarket storage temperatures 4°C to 2°C could lead to 19% reduction in meat waste, albeit at an increased cost due to energy requirements.[743]
Increased delivery frequency.	RFS: spoilage waste.	This reduces dwell time in distribution centres between suppliers to RFS outlets.	A study[744] comparing four retailers in Norway found that those with more frequent deliveries had lower levels of food waste, with notable impacts on meat, dairy, and convenience food waste (60%-100% reduction) as well as on fruit and vegetable waste (50% reduction). ReFED estimates that increases in delivery frequency across US retailers could divert up to 49,000 t of food waste annually.[429]
Inventory management tools for traceability.	RFS: spoilage waste.	Labelling products to track their progress along the supply chain is key to identifying waste hotspots, supply chain disruptions, and aligning supply and demand. Important technology in this space includes 2D barcodes[745] (see section 4.2).	GS1 has reported that Woolworths' trials of 2D barcodes in Australia has improved traceability and reduced food waste by 40%.[746] As this is emerging technology, data are limited.
Minimised on hand inventory.	Retail: spoilage waste.	Reduces the amount of stock held in distribution centres or the back of stores. While 'safety stock' is needed to account for unanticipated spikes in demand, reducing the amount of product sitting in storage (and losing shelf life) can improve product freshness and reduces waste.[747]	ReFED estimates that decreases in minimum order sizes across US retailers could divert 61,000 t of food waste annually.[747] However, there is little to no scientific study evaluating the efficacy of this intervention, nor available real-world data. Considerations such as the impact of smaller orders on transport and transport related emissions would need be understood before rolling out such an intervention. Note that on-hand inventory in distribution centres or out the back of stores is different to overstocked shelves. Overstocking is also an issue but has different drivers and therefore different solutions. Overstocking is addressed in box 6.
Stock rotation.	Retail: spoilage waste.	Organising and managing inventory ensures older stock is sold before newer stock.	Stock rotation within stores and on shelves is an expected routine to ensure that expired stock is not on shelves.[748] ReFED estimates that 350,000 t of food waste could be diverted in the US if products that expire first are sold first.[417] This method does become challenging for products that may not have an expiry label and are highly perishable (e.g. fresh produce) Generally, empirical evidence for the specific effect of stock rotation on food waste is lacking.

Waste tracking and measurement			
Intervention	**Type of waste**	**How it is used**	**Evidence of effectiveness**
Apps and programmes[394]	Retail: preparation waste and spoilage waste. Food service: plate waste, preparation waste, and spoilage waste.	Apps and programmes can measure, visualise, and track waste within businesses. E.g. Waste Master,[749] Leanpath,[750] Smart Kitchen,[751] and Winnow.[752] Retailers can also build or modify their own in-house inventory software to track food waste and prioritise actions.	According to the EECP, restaurants using Waste Master[749] can decrease their food waste by 30%-50%, sometimes more.[749] Analysis of 735 hotels, restaurants, and canteens in Europe found that simply measuring food waste led 61% of organisations to minimise their waste.[753] ReFED estimates that waste tracking in food service has the potential to highlight areas to optimise menus and reduce cost.[415] In the US, keeping track of waste could help divert over 1 Mt of food waste[415] (but by no means only through improved menu planning, the impact of which is unquantified).
Training and toolkits for food waste measurement and reduction.[394]	Retail: preparation waste and spoilage waste. Food service: plate waste, preparation waste, and spoilage waste.	Typically provide guidance on food waste measurement and reduction techniques. Examples include: Unilever Food Services' 'Wise Up On Waste' Toolkit,[754] New South Wales' EPA 'Your Business is Food' programme,[755] and the Smart Kitchen Initiative in the United States.[756]	Evidence from real-world trials suggests that training and toolkits can effectively reduce food waste. Results from San Diego Smart Kitchens pilot programme saw a 42% reduction in food waste.[757] Training of food service workers in 15 US schools resulted in significant food waste reductions across fruit (14%), vegetables (7%), and milk (4%).[758] Similarly, training of kitchen staff in restaurants[759] and hospitals[760] has also proven effective at reducing pre-consumer waste.

Annex 4: Household food waste measurement methodologies

Methods for calculating household food waste can vary between countries and can make household food waste data comparisons challenging.[761] Table 16 features countries identified to have better household food waste data by the UNEP *Food waste index report 2021*.[482] Solid waste studies are typically conducted for municipal solid waste, where categories of waste (for example, organic or food waste) are physically separated from general waste to be quantified and a proportional value is derived.[762,763] Direct measurement through food waste bin audits is a more detailed method than solid waste studies as it separates food waste specifically from municipal waste. Sorting can include discrete categories such as type of food (for example, fruit, vegetable, meat, etc.), specific food items (for example, tomatoes), and whether the waste was avoidable or unavoidable.[403,764] The methodology column in table 16 classifies items into solid waste studies or food waste bin audits, based on information that was readily available and identifies whether mixed methodologies or additional sources (such as surveys and diaries) were utilised for household food waste data.

Table 16: Country comparison of household food waste data and how it is measured. Abbreviation: kg = kilograms, Mt = megatonne, m = million, n = number of participants for whom data is reported, pp= per person, t = tonnes, UNEP = UN Environment Programme.

Country	Household food waste data	Methodology	Description of methodology	Factors to consider
Australia	Produced the largest proportion of food waste (38%), around 3.1 Mt (based on the reference year 2018-2019).[57]	Unknown. Survey, diary, and bin audit.	Methodology was unclear; however data for estimated food loss was across the entire supply chain. Data from 169 sources across seven types of information routes were used for the overall analysis. Data quality was scored as part of the management system and the average score was 3.8/5.[57] Western Australia published their household food waste measurement methodology for data collected between 2020 and 2021 using a survey (n=324), an electronic diary (n=177), and a bin audit (n=103).[765]	The rounded figure of 38% is in comparison to sectors like primary production (20%), processing (15%), distribution (3.1%), retail (6.3%), hospitality (15%), and institutions (3.0%).[57]
Austria	Avoidable food waste ranged between 9.5-25.5 kg per capita. Rural areas produced less waste than urban areas.[761]	Food waste bin audit.	130 samples were collected from 9 representative rural municipalities and 1 urban municipality over 20 days in 2009. Food waste was manually sorted from residual waste and weighed.	Researchers notes that the state of degradation did make it difficult to categorise and identify items. Additionally, the values only give a snapshot of food waste in time.
Canada	79 kg per capita (estimated for 2016).[482]	Solid waste study.	There is no published national statistical data on household food waste. National residential food waste estimates were based on 56 studies conducted between 2008-2018 and the known quantity of waste provided by Statistics Canada for 2016.[763]	Surrogate data was used for regions that did not have data available, and this could have applied to the calculation of food waste.[763]

Country	Household food waste data	Methodology	Description of methodology	Factors to consider
Denmark	Produced 103 kg per household per year of avoidable food waste and 80 kg of unavoidable food waste (based on data collected between 2011 and 2012).[764]	Food waste bin audit.	This analysis is based on 1,474 households across 5 municipalities. Samples were collected three times to account for any periodic variation in waste.	Recent publication from 2017 was not accessible in English.
Germany	59% of the food waste generated in the supply chain is from households, as a proportion of 10.9 Mt (based on data for 2020).[766]	Unknown.	Unknown, but has been stated to be within the scope of EU reporting requirements,[767] which could include waste compositional analyses or direct measurements. Questionnaires and surveys are not used as measurement method for households.[762]	59% is in comparison to processing and manufacturing (15%), primary production (2%), restaurants and food services (17%), and distribution (including retail at 7%).[766]
Ghana	Food waste was differentiated between high- and middle-class income areas; however, both were around 0.2 kg pp per day (based on data collected between 2013 and 2014).[768]	Solid waste study.	A large number of samples of general waste were collected from ten regions (in some regions over 1000 samples). These were manually sorted and weighed at a sorting centre.	This was a national municipal waste study. Food waste comprised of 44% (high-income) and 51% (middle-income) of the general household waste collected.
Malta	52% of general household waste contains food.[769]	Solid waste study.	No methodology stated; however data is based on a 2011-2012 survey by the National Statistics Office.	The survey is not accessible, however a publication from the EU has classified this survey as a waste compositional analysis. A value of 0.38 kg of food waste pp per day is implied for households.[770]
Netherlands	Produced around 34 kg of solid food waste per capita (based on data collected in 2019).[573]	Surveys, solid waste study, and food waste bin audit.	Multiple method study. Surveys (n=1000) captured self-reported data of solid food waste (solid, thick liquid, and dairy) and liquid waste. Municipal waste was collected from 130 households across 13 municipalities. Food waste was manually separated into categories.	Solid and liquid food waste is calculated separately. The total of 34 kg of solid food waste includes approximately 27 kg of food waste from municipal waste audits and an estimation of approximately 8 kg of food waste through other routes.
Norway	Produced 80.2 kg of total food waste per capita, of which almost 58% was edible food waste (based on data collected in 2011).[771]	Solid waste study and food waste bin audit.	Waste study of 220 individual households. Data was collected from 4 municipalities where food waste was not separated and assumed to be collected as municipal waste. Sampling areas were informed that samples would be collected anonymously on a random week and households could opt out of being sampled. Municipal waste was weighed and then food waste was separated into edible/non-edible categories and other sub-categories (fruit and vegetables, bread, leftovers, etc).	The study noted that a third of the edible food was still in the original packaging.

Country	Household food waste data	Methodology	Description of methodology	Factors to consider
Saudi Arabia	Produced 105 kg of food waste per capita.[482]	Solid waste study.	The methodology for measuring household food waste is unclear.	The UNEP Food Waste Index Report 2021 indicated that the sample size for households and methodology was unclear, but categorised that a waste compositional analysis was carried out.[482]
Sweden	Produced 94 kg of food waste pp, and 68 kg of food pp if excluding waste down the drain (based on data collected in 2018).[772]	Solid waste study.	The methodology for measuring household food waste is unclear.	94 kg accounts for approximately 71% of the total food waste from the supply chain. Avoidable food waste measured at 26 kg pp disposed via the drain and 19 kg of avoidable food waste pp is either residual waste, separated waste, or in home composts.[772] Sweden has been collecting data on national food waste since 2012.[773] It is likely that Sweden would be using the food waste measurement methodology set out by the European Commission.
UK	Produced 70% of food waste, around 6.6 Mt. Around 4.5 Mt of food waste was avoidable (based on 2018 data).[409]	Solid waste study.	Compositional analysis of waste collected by 129 local authorities from general waste, kerbside food waste, food wate contaminated recycling, and waste recycling centre.[774]	70% is a high value as the proportion of food waste generated is calculated post-farm gate (i.e. waste generated after primary production).[409]
US	Produced 153 kg of residential food waste per household per year[775] (59 kg per capita[482] and food waste accounted for 17% of total household waste).[775]	Unknown.	The enhanced generation methodology infers household food waste using data estimates from 12 studies published after 2007. Extrapolated data is generalised based on assumptions and multiplied by a 'generation factor' to calculate estimates.[776]	Households in the US are estimated to contribute to 24% of the food waste in the supply chain compared to 39% in the industrial sector.[775] The UNEP Food Waste Index Report 2021 suggests that US waste per capita values are only comparable to Australia and the UK if both residential and food service are combined (estimated at 123 kg per capita per year). The methodology is not recommended by the UNEP report for comparing data over time.[482]

Annex 5: Household food waste prevention interventions

There is a growing number of studies on household food waste,[777] and many interventions that have been proposed as solutions.[778,779] However, selecting appropriate interventions for food waste prevention can be challenging. Table 17 provides an introductory analysis of a few types of interventions. Table 18 describes multipronged interventions combining multiple approaches. Table 19 lists several tools that also play a role in household food waste prevention. These tables have been adapted from Auckland Council's review of interventions to reduce household waste in general, of which a significant number of interventions were targeted at food waste.[780]

Table 17: Singular intervention strategies and evidence for their use. Adapted from Auckland Council.[780] Abbreviations: LFHW = Love Food Hate Waste, m = million, MTurk = Mechanical Turk.

Type of intervention	Example study	Goal	Was it successful?	Context	Conclusion and considerations
Community workshops	Canadian multi-method study.[781]	To raise awareness about food waste and reduce food waste generation.	Some increase in participants' motivation to reduce food waste.[781] This did not translate reduced food waste: there was no difference in the amount of food wasted compared with before the intervention..[525]	This study tested multiple interventions over 12 weeks and included workshops for one of the targeted groups. Workshop participation rates were low, even when childcare was provided to encourage participation.	Empirical evidence for community workshops is not strong. Community engagement strategies that build capabilities may be more effective, especially for individuals who are already motivated to do so.[394]
Consumer challenges	NZ Food Waste Warriors Challenge in 2022.[533]	Not published.	Social media reach of 15.1m, but no detail on food waste outcomes.[782]	Campaign of online content in partnership with the One NZ Warriors. There was an incentive to win a pantry and fridge makeover worth $1,500.[533]	Challenges may work, but there is insufficient evidence on their effectiveness.[394] It may be valuable to undertake further research in this space, and to collect data on outcomes related to food waste as well as campaign reach.

Type of intervention	Example study	Goal	Was it successful?	Context	Conclusion and considerations
	Brisbane's Save Money Save Food text challenge.[783]	Not published.	Not published.	Ongoing campaign. Residents are encouraged to text a free number to receive 10 text messages with suggestions about how to reduce their food waste over a three-week period. The challenge is designed over the three food categories that were recognised as Brisbane's most wasted foods; meat, salad greens, and bread. A survey at the end of the challenge gives residents a chance to win a food saver pack that includes seeds, 'use it up' tape, a cookbook with food waste tip, and food covers.[783]	
	Dutch 100-100-100 challenge.[784]	To test if informational strategies reduced volume of residual waste. This includes food waste.	There is some evidence here that waste prevention behaviours were improved compared to the control group. Measured waste findings were however limited.	This study did not specially focus on food waste but challenged 100 households to live 100% waste free for 100 days in 2015. This included households needing to actively engage with weekly assignments and waste comparisons. Food related assessments related to preparation waste, shopping, list making, and recording about leftovers.	
Cooking classes	No data.				No evidence for cooking classes alone as a primary food waste reduction intervention, however an exploratory study suggested they can help with acquiring new skills.[785] Cooking classes have been utilised in tandem with other strategies (see table 18). Trials of cooking classes for food waste prevention may find it valuable to evaluate efficiency, effectiveness, and scalability.

Type of intervention	Example study	Goal	Was it successful?	Context	Conclusion and considerations
e-Newsletter	Asda – retail influence on consumer behaviour in the UK.[786]	Reducing reported food waste.	Self-reported reduction in food waste was observed in all arms of the study, including the control group, suggesting the e-newsletter was not effective.	A UK retailer compared the effectiveness of food waste messaging in e-newsletter, social media, and print/digital magazines with a control group comprising people who reported not seeing any of the interventions. The trial ran over six months and included 2,018 participants across all the groups.	The Asda study suffers from a low response rate, with 2,018 respondents fully completing all data collection activities out of 20,000 customers targeted. Further investigation may be useful. Auckland Council suggested that e-newsletters may be more suited as reminders rather than a primary intervention.
Food diary	Literature review on measurement methods (no specific location).[787]		Not applicable.	Records how food is handled and usually includes a measurement component, for example, cups of rice discarded. Variations can also include app-based diaries or taking photos of the waste.	There is no empirical evidence of the use of diaries causing measured food waste reduction.[787] It is plausible that a diary has potential to reduce food waste as it makes the waste quantity visible and raises awareness about the issue.[279] Separately to their use as an intervention, diaries may also be useful for measuring food waste in evaluation of other interventions. They may underreport food waste,[788] but they are thought to be more reliable than surveys.[787]
Meal kits	No data.				The use of meal kits and meal kit services may show some potential for reducing food waste at home;[459] however this is still in the early stages of research. There is a gap in the data on how much food waste occurs at the supplier itself. There is also a tension with excess packaging to consider; however one US study has reported that a meal kits' life cycle environmental impacts were lower than comparative meals made with store bought items.[459]

Type of intervention	Example study	Goal	Was it successful?	Context	Conclusion and considerations
Online quizzes and games	Canadian multi-method study.[781,525]	To raise awareness about food waste and reduce food waste generation.	In common with all arms of the study including the control group, there was no difference in the amount of food wasted compared with before the intervention, but the gamification arm had higher levels of participation and greater self-reported food waste reduction.[525]	This study utilised a simple game design and the design of the game may have impacted engagement with quizzes.	The Canadian study was relatively small and did not report whether it was sufficiently powered to detect differences between the treatment arms. There is scope for more research here. Studies on apps using games and quizzes for food waste prevention are emerging, some of which are student led projects and focus on the development of the software rather than measured food waste reduction.[789]
Prompts	US study on consumer willingness.[790]	To determine if a person was willing to reduce food waste.	There was no difference in willingness to reduce waste between those who received various prompts and those who did not receive a prompt, although recipients of some of the prompts increased their perception of food waste as a social problem compared to the control group.	Participants (n=261) were recruited from the US using Amazon's MTurk crowdsourcing website, and randomly assigned to see one of three visual prompts or to a control condition.	Prompts are likely to be more useful for people who already engage in food waste reduction practices, or are likely to make behavioural changes to reduce food waste at home.[524] There are other types of prompts such as magnets or signs that act as reminders about particular food waste preventions behaviours,[781] and placed where the prompt is useful.[779] For example, an "eat me" sign on leftovers in the fridge. Auckland Council supported exploring the delivery of prompts as an intervention.[780]

Type of intervention	Example study	Goal	Was it successful?	Context	Conclusion and considerations
	Literature review of different types of interventions.[779]	Scan of practical and academic evaluations of prompts.	Two interventions showed measured food waste reductions; however, these were at a buffet restaurant and at a university dining facility. No data was provided on households.		
Social media	Asda – retail influence on consumer behaviour in the UK.[786]	Reducing reported food waste.	Self-reported reduction in food waste was observed in all arms of the study, including the control group, suggesting the social media delivery was not effective.	A UK retailer compared the effectiveness of food waste messaging in e-newsletter, social media, and print/digital magazines with a control group comprising people who reported not seeing any of the interventions. The trial ran over six months and included 2,018 participants across all the groups.	The retail study did not find any effect of social media on food waste, which the authors note was in contrast with lab-based studies. Eat Well Tasmania viewers found that learning to set up a 'use it up' area, learning new cooking skills, and leftover food management practices as quite helpful. The authors concluded that social media might be a useful tool to raise awareness. Decision makers may need to consider the efficiency and effectiveness of a social media campaign if it is used as the only intervention for food waste prevention. The use of social media may be valuable to support a wider campaign to raise awareness. Auckland Council also recommended not to pursue social media campaigns as a primary intervention tool.
	Eat Well Tasmania.[791]	Reducing food waste and eating well.	No, average food waste reduction based on survey data was not statistically significant.	This initiative utilised three 10-minute videos aimed at younger households (18-35 year olds) targeting specific behaviours such as eating old food first; eating/storing leftovers; and storing food correctly.	

Table 18: Multipronged interventions and evidence for their use. Adapted from Auckland Council.[780]

Name of the intervention	Components of the intervention	Food waste reduction data	Context	Conclusion and considerations
Food Lovers Masterclass[792]	Workshops; emails; video content; incentive packs.	Nearly half of respondents to a survey at six weeks after the workshop reported less household food waste than in a survey before the workshop.[491]	This intervention is delivered by Waste-Ed with Kate across NZ. Alongside the workshop there are also surveys, emailed video content, and text surveys. The workshops have been well attended across the country by attendees that sign up at varying costs based on council funding. Some locations also have incentive packs that include tools like storage packs or “eat me” stickers. Food waste measurement strategies have included using an ice cream container.	Because people self-select into the workshops, participants are likely to be highly motivated to reduce their food waste. More evidence is needed on whether these types of workshops can be effective more broadly.
HomeLabs[793]	Information; kitchen caddies; food growing kits; food boxes.	Households were able to reduce food waste by 28% over the course of the intervention.	This was a small, coproduced intervention which included just 5 households in Dublin. Different elements of the intervention were delivered each week for a total of 5 weeks.	It is not possible to draw conclusions of the programme's effectiveness on the basis of this small study. The study also did not include information about food waste reduction after the intervention. An individualised intervention such as the HomeLabs would be challenging to deliver at a large-scale as it is resource and cost intensive.
Reduce Food Waste, Save Money [794]	Information; website; emails; postcards; fridge magnet; food storage container; freezer stickers; grocery list pad.	Avoidable food waste decreased by 30% and was statistically significant when compared to the control group.	This study had multiple interventions that were used in a two week period for 54 single family households in a Canadian city (London) with no kerbside food collection programme. The methodology directly collected garbage samples and manually sorted and weighed food waste.	The study was focused on single family household units and so excluded other types of family units or those in apartments. Understanding whether the food waste practice was sustainable over time was out of scope for the study.

Name of the intervention	Components of the intervention	Food waste reduction data	Context	Conclusion and considerations
Waste Watchers[795]	Educational website; weekly reminders; laboratory visits.	The intervention showed a 28% decrease in household food waste.	In this study, 53 individual families (targeting one person in the household, primarily female) were recruited to participate in a five-week educational intervention delivered through a website[796] with downloadable content, podcasts, infographics, videos, and text. Each week, participants were reminded to check the website for new content, and regular surveys. Participants also conducted a laboratory visit pre-and post-intervention to observe and assess food-based habits at home.	The study suggests that policy interventions such as date labels, packaging for longer shelf life, and retail purchasing practices may have an impact. Those who dropped out of the study were from lower income households.
Weeknight Supper Savers	Online cooking classes; text messages; cookbook; child friendly knife; meal and shopping planners; 'Eat first' container; food storage guide	Waste audits suggested total food waste decreased by 7.4%.[797]	This was a 4 week Canadian study focusing on 18 families with children (9-12 years) aimed at the whole family. The aim of the study was to reinforce food literacy and also reduce food waste.	The study did not include a control group and therefore the effectiveness of the interventions are harder to determine. The sample size is also small, and the households were mainly white and had high incomes. Additionally, 17 mothers and 12 fathers participated, but the text messages were targeted at mothers and children.

Table 19: Tools used in New Zealand or internationally to prevent food waste and evidence for their use. Adapted from Auckland Council.[780] Abbreviations: AI = artificial intelligence.

Example of tool	Stage(s) of intervention	How it is used	Factors to consider	When will it be available to scale?
AI, apps, and websites	Planning. Preparing.	There are recipe generators that can find recipes based on the ingredients available. PAK'nSAVE have Savey Meal-bot website that utilises OpenAI's ChatGPT to create recipes.[798]	These tools are new, and there is not yet evidence that they have contributed to food waste reduction.[799] Uses of these tools will also require a warning to avoid glitches if the app recommends using non-grocery items.[800] Apps that monitor and track food waste may need manual input of produce, which may be a barrier to use.	Currently available.

Example of tool	Stage(s) of intervention	How it is used	Factors to consider	When will it be available to scale?
Ethylene scavengers	Storage.	Ethylene scavengers slow down the ripening process and increase the shelf life of some fruits and vegetables.[801] They are mostly used to preserve produce after harvest and before it reaches consumers (see table 6). There are some commercial examples for households such as: Bluapple®,[802] Fridge Friend®,[803] and Purifie® FridgeMate.[804]	There is a lack of experimental research on the effectiveness of ethylene scavengers at a household level, and furthermore its ability to prevent food waste at this scale.[805] It has been used as part of one wider food reduction study, but its use was not the major focus.[806]	Currently available, but there is little empirical evidence about household use.
Kitchen products or practices	All stages.	There are many examples of simple products such as storage containers or pouches, food vacuum sealers, dehydrators, and portion measuring tools. There are also traditional techniques to preserve food at home like fermenting and canning.	People wanting to try fermenting and canning may need support to ensure that the food remains safe.	Currently available.
Smart bins	Disposal.	There is a case study of 'BinCam', a disposal bin equipped with a camera that shares images to a social media group in order to influence food waste behaviour.[807] Another product on the market is Mill, an in-home food recycling system that converts food waste into dry animal feed.[808] This is more applicable for capturing value from food waste (see *Beyond the bin: Capturing value from food waste*).	BinCam was experimental. There are privacy and data issues that arise from this method and it is not recommended to prevent food waste.[780]	Mill is available internationally but not in NZ; limitations include cost to scale and requirements for power and internet.
Smart fridges	Storage. Planning. Preparation.	Smart/intelligent fridges can work in tandem with apps to support food management practices at home.[479] This could also incorporate cameras that can relay images back to the user about the contents in the fridge. Recent models also claim to use AI to support with preparation.[809]	The use of gamification to teach people how to sort their fridges to reduce food waste are still in early stages of research.[789] We still do not know about the effectiveness of smart fridges on food waste prevention. Furthermore, the cost of owning a smart fridge is a barrier to implementation.	Currently available, costly to scale.

Abbreviations

1D	One dimensional
1-MCP	1-Methylcyclopropene
2D	Two dimensional
3D	Three dimensional
AI	Artificial intelligence
APS	Advanced planning and scheduling
AR	Augmented reality
BCG	Boston Consulting Group
BERD	Business enterprise sector research and development
BMW	Biological municipal waste
CODC	Central Otago District Council
CoRE	Centre of Research Excellence
CRC	Cooperative Research Centre (Australia)
CRISPR	Clustered regularly interspaced short palindromic repeats
DEFRA	Department of Environment, Food and Rural Affairs (UK)
DIGAD	Dairy Industry Good Animal Database
DLT	Distributed ledger technologies
E-bins	Electric bins
EECP	European Cluster Collaboration Platform
EFWA	End Food Waste Australia
EPA	Environmental Protection Agency
ERP	Enterprise resource software
FAO	Food and Agriculture Organization (of the UN)
FEFO	First expired first out
FIAL	Food Innovation Australia Limited
FIFO	First in first out
FLW	Food loss and waste
FSANZ	Food Standards Australia New Zealand
GDP	Gross domestic product
GDSN	Global data synchronisation network
GERD	Gross domestic sector research and development
GMO	Genetically modified organism
GovERD	Government intramural research and development
GPT	Generative pre-trained transformer (as in ChatGPT)

HERD	Higher education research and development
HortNZ	Horticulture New Zealand | Ahumāra Kai Aotearoa
IoT	Internet of things
IP	Intellectual property
IT	Information technology
kg	Kilograms
KPI	Key performance indictor
LED	Light emitting diode
LiDAR	Light detection and ranging
LTIB	Long-term Insights Briefing
m	Million
MBIE	Ministry of Business, Innovation and Employment | Hīkina Whakatutuki
MBT	Mechanical-biological treatement
MfE	Ministry for the Environment | Manatū Mō Te Taiao
MJ	Megajoules
ML	Machine learning
MOU	Memorandum of understanding
MPa	MegaPascal
MPI	Ministry for Primary Industries | Manatū Ahu Matua
MSW	Municipal Solid Waste
Mt	Megatonne
MTurk	Mechanical turk
NAIT	National Animal Identification and Tagging
NGO	Non-governmental organisation
nm	Nanometres
NZFIN	New Zealand Food Innovation Network
NZFN	New Zealand Food Network
PAYT	Pay as you throw
pp	Per person
QR	Quick response
R&D	Research and development
RFID	Radio frequency identification
RFS	Retail and food service
RGB	Red, green, blue (cameras)
RMP	Risk management plan

SAP	Sector action plan
SDG	Sustainable Development Goal
SFF	Sustainable Food and Fibre (Futures Fund)
SME	Small and medium sized enterprises
SWOT	Strengths, weaknesses, opportunities, threats
t	Tonnes
ToC	(MfE's) Theory of Change
TOC	Total organic carbon
UNEP	UN Environment Programme
UoA	University of Auckland | Waipapa Taumata Rau
UoO	University of Otago | Ōtakou Whakaiu Waka
UPC	Universal product codes
UPF	Ultra-processed foods
USD	US dollars
UV	Ultra-violet (light)
UV-C	Short wavelength ultraviolet (light)
VR	Virtual reality
WRAP	Waste and Resources Action Programme

Glossary

2D barcode	A graphical image that stores data in two dimensions (vertically and horizontally), for example, a QR code. In the food supply chain, these codes are used to store product information and improve product traceability and inventory management.
Aotearoa New Zealand	The terms Aotearoa New Zealand, Aotearoa, and New Zealand are used interchangeably in this report.
Asexually propagated	Also known as vegetative propagation, where growing new plants does not require seeds. Plants are grown instead from cuttings, tubers, roots, or other plant material. For example, new potato plants are grown from potatoes.
Brix	A measure of dissolved solids in a liquid. Commonly used to measure sugar proportions of fruit.
Bobby calves	Surplus calves from the dairy industry that are sent to abattoirs/processors usually at four days old.
ChatGPT	An interactive generative AI interface which can have human-like conversations.
Cold chain	Temperature-controlled supply chain that keeps products – in this context, food – at the correct temperature while being transported and stored. Maintaining correct temperatures throughout the chain requires significant logistical capacity.
Colostrum	Milk from the first four days after calving, which has a different composition to ‘normal’ milk.
Cosmetic specifications	Specific requirements for fruit and vegetables regarding their colour, size, and shape. Produce must meet these specifications in order to be considered marketable. See also imperfect produce.
Counterfactual	An alternative state. In research and evaluation an ideal counterfactual is identical to the actual state in all but the variable of interest. When there are differences between the counterfactual and the actual state, outcomes may not be due to the variable of interest but to these differences.
Cultivar	A cultivated variety of a plant species that has been bred selectively to produce desirable attributes such as increased yield, disease resistance, colour, flavour, size etc.
Casualty animals	Animals that die or are euthanised on farm, includes all ages of animals (i.e. slinks).
Demand forecasting	The process of predicting future customer demand over a specified period of time.
Digitalisation	Converting operations and processes from analogue to digital. Not to be confused with digitisation.
Digitisation	Converting specific pieces of data from analogue to digital. Not to be confused with digitalisation.
Distributor (or distribution)	A business that has a relationship with processors and manufacturers, responsible for getting their products to other parts of the supply chain, often to retailers. Distinct from wholesalers (who also purchase from processors/manufacturers and sell to retailers) because they are

	usually associated with single brands of a given product while wholesalers may offer multiple competing brands.
Downstream	Parts of the food supply chain that are closer to the consumer end relative to the part of the supply chain being discussed. For example, retail is downstream of processing and manufacturing (also see upstream).
Dwell time	The amount of time goods spends sitting idle at a given point in the supply chain. This can occur at various stages, such as at a manufacturing site, within a warehouse, during transportation stops, or at a port waiting for customs clearance.
Food	In this project, food is intended to capture both food and beverages. Unless specified, we are referring to food intended for human consumption.
Food delivery services	In the context of this report, food delivery services refer to third party applications and digital platforms that enable delivery of food from food service providers direct to households.
Food loss	Food that is discarded during the production or processing stages of the supply chain. Food discarded after this stage (i.e. in retail, food service, and household settings) is referred to as food waste.
Food loss and waste	For the purposes of this project, food loss and waste is defined broadly and inclusively. Any food or drink that isn't utilised according to its original purpose, as well as by-products and non-edible components of food are included. We give regard to the variable understandings of food and food waste. The entire supply chain is in scope.
Food recovery hierarchy also referred to as 'the hierarchy'	A framework for thinking about solutions to FLW, prioritising interventions according to which types of solutions are likely to deliver the most environmental and social good. The food recovery hierarchy is a modified version of the waste management hierarchy, specific to food. There are many different versions of the food recovery hierarchy. Also known as the 'food waste hierarchy' or the 'food waste management hierarchy'.
Food rescue	The process by which surplus food is captured for human consumption, typically as part of a charity model – but this isn't inherent in the term.
Food service	A part of the food supply chain that prepares food for immediate consumption on-site, takeaway, or delivery, for example, restaurants, catering services, and cafeterias.
Food supply chain	The pathway from where the raw ingredients that will become our food originate, to the places where we eat, form the food supply chain. Specific pathways differ for different kinds of food.
Food system	While food supply chains are a part of food systems, food systems is a more holistic term. The OECD definition of food systems captures the meaning well: "Food systems refers to all the elements and activities related to producing and consuming food, and their effects, including economic, health, and environmental outcomes."[810]
Food waste	Food that is discarded after the processing stage of the food supply chain, i.e. in retail, food service, and household settings. Food that is discarded during the production and processing stages of the supply chain is referred to as food loss.

Genotype	The genetic makeup of an organism.
Germplasm	Genetic resources such as seeds, DNA, rootstock etc. usually used for research or breeding cultivars.
Gleaning	Gathering leftover crops from commercially harvested fields or on fields where the producer has decided not to harvest (for example, because it would not be economically profitable).
Imperfect produce	Fruits and vegetables that do not meet cosmetic specifications for size, shape, or colour, but are remain nutritious and safe to eat. See also cosmetic specifications.
Intervention	A deliberate action or set of coordinated actions designed to change specific behaviours or practices to achieve a particular outcome. In this report, we focus on interventions which aim to prevent FLW.
Manufactured or manufacturers	Involves machinery, automation, and assembly lines to produce packaged foods like snacks or ready-to-eat meals. Manufacturers are the actors who carry out manufacturing.
Mastitis	Inflammation of mammary glands in this report specifically of cows udders. May be caused by bacterial infection and require antibiotics.
Milk solids	The components of dairy after water has been removed. Used as a standard measure of mass/yield in the dairy industry.
Overproduction	In this report, we are referring to the overproduction of food. This is when the volume of food produced far exceeds the demand in the market. This often occurs as a strategy to avoid risk.
Overstock and overstocking	Overstocking is the practice of purposely keeping inventory levels higher than what is needed. In this report we apply this term to both household and retail food waste. In retail, it means stock is surplus to what is realistically expected to sell within a given timeframe in order to fill the shelves. Overstock is surplus product that results from overstocking.
Packhouses	These are sites of post-harvest sorting and grading of produce. Depending on the industry and the size of the operation, packhouses may be located on farms or at a second location. Packhouses are considered part of the production stage of the supply chain (also see post-harvest).
Phenotype	Observable traits, for example, size. Phenotypes are a result of the interaction between genotypes and the environment.
Plate waste	Food that is served to customers but not eaten.
Post-harvest	A sub-stage of the supply chain within production, where produce is sorted and graded, often in packhouses (also see packhouses).
Precision agriculture	A farm management technology that optimises the growth and harvest of crops.
Preparation waste	Food that is discarded during the preparation of food for sale or consumption.
Price-taker	Stakeholders that have lower market power in a stakeholder relationship. For example, farmers are identified as price-takers as they have little influence over the price they receive for the commodities they produce from processors, wholesalers, and retailers.

Processed and processors	Any modification to food, including the removal of inedible parts or the addition of other ingredients. Processors are the actors who carry out the processing.
Producers	People that use natural resources including land, water, seeds, animals, to generate food or ingredients of food. Also known as farmers or growers.
Quality specifications	The set of criteria that food products must meet to ensure they are suitable for consumption, sale, or further processing and maintain food safety across the food industry. Specifications can vary by food type and regulatory requirements, but typically include physical attributes (for example, size, weight, colour), safety standards (for example, pesticide residues or microbiological limits), chemical composition (for example, nutrient or moisture content), and sensory characteristics like taste, texture, or aroma.
Research and development (R&D)	Activities carried out by public or private institutions that seek to resolve scientific or technological uncertainty, creating new knowledge, improved processes, services, or goods.
Retailers	Businesses that sell food products directly to consumers. This can include a variety of outlet types, from large supermarket chains and specialty food stores to local grocers, farmers' markets, and online food retailers.
Secondary market	A marketplace where food products, which are not sold through primary channels (typically retailers), find a different route to consumers. This can include, but is not limited to, overstocked, returned, imperfect, or near-expiration products that are still safe and usable but may not meet the primary market's stringent criteria for aesthetics or quality.
Serving waste	Food that is wasted after being prepared and offered to the consumer but not taken (for example, table bread rolls).
Slinks	Calf and lamb casualties on farm.
Spoilage	Food that is unfit for human consumption due to damage or deterioration.
Stock rotation	An inventory management practice governing the placement of stock in warehouses and retail settings to determine the order in which stock is sold.
Subclinical	Pertains to a disease that does not show obvious symptoms. For example, subclinical mastitis in a dairy cow may not show differences in the visual attributes of the milk, but changes are detected when testing milk composition (i.e. increase somatic cell counts).
Surplus food	Quality, safe, edible food that exceeds the need or demands of a population and is at risk of being wasted if it isn't used. It is distinct from food that is spoiled, damaged, contaminated, past its use by date, or otherwise no longer fit for human consumption.
Take-back agreements	Common terms of trade between retailers or wholesalers and suppliers that are structured so that retailers do not pay for the quantity of product ordered, only the quantity sold, with the supplier responsible for the costs of disposing of any unsold product. These are also sometimes called 'sale and return' agreements or 'scan based trading contracts'.

Terms of trade	In this context, the conditions and agreements under which trade is conducted between parties involved in the procurement, production, and distribution of food.
Topographies	The surface features of an area, for example, hilly, flat, mountainous etc.
Total organic carbon	The concentration of carbon in a compound. Often used as a proxy for water quality.
Trim or trimmings	By-products or waste material that are generated when a primary food product is cut, shaped, or processed.
Unprocessed	Plants or animals that are harvested directly from the land or sea.
Upcycling and upcycled food	Creating new food products from by-products or unmarketable foods such as stale bread, offcuts, or damaged produce. Upcycling is the process whereas upcycled food is the output from upcycling.
Upstream	Parts of the food supply chain that are closer to the production end relative to the part of the supply chain being discussed. For example, processing and manufacturing is upstream of retail (see also downstream).
Vertical integration	A business model whereby a single company (for example, a large retailer or wholesaler) owns and controls multiple stages of the supply chain.
Wholesaler	An intermediary between producers (such as farmers, growers, or manufacturers) and retailers or other businesses that sell directly to consumers. Wholesalers purchase large quantities of products and on sell them in smaller quantities. Distinguished from distributors (who also purchase from processors/manufacturers and sell to retailers) by purchase of large quantities and coverage of multiple competing brands.
Yield and yield potential	Yield is the mass of food or food ingredient generated during production by producers. For example, the tonnes of apples harvested in an orchard. Yield potential is the expected yield when there are no limiting factors to growth other than genetics.

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