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Exploring Drivers and Mitigation Strategies for Food Manufacturing Wastes in the Circular Economy Using Rich Pictures

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ABSTRACT

This study aims to identify the main types, drivers, and solutions for food loss and waste (FLW) as reported by stakeholders within the UK food manufacturing sector from a Circular Economy perspective. Based on insights from diagramming-based workshops involving 35 participants working in an organisation in the sector, FLW occurs primarily as a result of it either being unwanted by the primary consumer or due to it being unsafe to consume. Drivers relating to internal considerations include machinery faults, human errors, and miscoordination across business functions, while external factors include sensitive product standards, uncertainties in demand forecasting, and constraints in raw material acquisition. Participants describe potential solutions including actions from across the Circular Economy playbook, including redistribution of surpluses, recovery and re-use of wastes and a particular focus on narrowing existing material flows through waste prevention. Of interest to parties seeking to understand the systemic drivers of FLW in the manufacturing sector, the results provide evidence for cross-sectoral collaboration in the design of interventions moving towards increased FLW reduction and productive use.

1 | Introduction

Estimates of the magnitude of global food losses and waste (FLW) place it between a quarter and a third of all food produced (Gustavsson et al. 2011; Kummu et al. 2012) leading to unnecessary depletion of the world's resources (UNEP 2021) and immense pressures on social, ecological, and planetary systems (Campbell et al. 2017). Economic losses caused by FLW have been estimated at $1 trillion annually (FAO 2014b), meanwhile 1 billion people face hunger and malnutrition (UNEP 2024). Global FLW reduction—as measured by the UN Environment Program and Food and Agriculture Organisation—has been integrated into the Sustainable Development Goals (UN General Assembly 2017), while national industrial sectors have responded with movements such as the UK Food and Drink Pact (formerly Courthauld 2030 Commitment) (WRAP 2020). Circular Economy packages now integrate FLW reduction and re-use (Ellen MacArthur Foundation 2021; Eurostat 2020) recognising the opportunities for sustainable resource management.

Interfacing between upstream production and downstream retail and consumption, the food manufacturing sector generates 11.2 Mt. of FLW in the EU each year (Eurostat 2024) and contributes to 16% of the UK's total annual FLW (WRAP 2022). Set aside

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from processors, food manufacturers take on activities traditionally associated with domestic food preparation (Beardsworth and Keil 2003), creating complex food products and meals. FLW in manufacturing companies is typically redistributed as surplus, or diverted to waste management routes ranging from nutrient recovery to landfill (Garrone et al. 2016). Manufacturers are constrained by both consumer expectations and legislative safety protocols (Alexander and Smaje 2008), requiring sophisticated coordination of manufacturing and waste management operations (Garrone et al. 2014).

The FLW burden of manufactured food products is subject to increasing attention (Espinoza-Orias and Azapagic 2018; Hirth et al. 2021) given the rising trend of industrialisation of food provisioning (Belasco 2018) evidenced by market shares. Yet, research generally makes a distinction between FLW in the upstream actors (producers, processors) and the downstream actors (retailers, consumers, the domestic sphere) (Gustavsson et al. 2011; Spang et al. 2019). Similarly, definitions of FLW split between *food losses* associated with harvesting and processing agricultural products and *food wastes* associated with retailers and consumers (FAO 2014a; Parfitt et al. 2010); meaning that FLW in food manufacturing, sitting at the overlap between these two definitions (Girotto et al. 2015), is understudied.

FLW can arise in the manufacturing stage due to a range of factors. Physical deterioration of food items and ingredients can arise during handling and transportation operations, driven by technical faults in machinery (Richter and Bokelmann 2016) or routine handling of fragile items (Secondi et al. 2019). Damaged items may be deemed unfit for consumption immediately, or may experience accelerated deterioration and be discarded during later screening stages (Raak et al. 2017). Food surpluses arise in manufacturers in the form of finished products and intermediate ingredients. Uncertainties and limitations in forecasting and placing orders can encourage the overstocking and overpreparing of products and ingredients, leading to surpluses (Mena et al. 2011; Richter and Bokelmann 2016). Underutilisation occurs when demand falls below supply (Gustavsson et al. 2011), leading to food items exceeding manufacturing internal use-by dates (Garrone et al. 2014). Food safety legislation prevents the sale of food beyond use-by dates or contaminated with foreign objects (Katajajuuri et al. 2014), with stock rotation and microbial testing adopted as common practices (Dymchenko et al. 2023).

Consumer expectations appear to affect fresh food products disproportionately (Stuart 2009; Thyberg and Tonjes 2016), leading to waste when undesirable products are not chosen for purchase (Buzby et al. 2015). Thus, food manufacturers undertake stringent quality control to meet retailer and consumer standards. Consumers are highly sensitive to visual defects (Jaeger et al. 2018), and more likely to deem a product sub-optimal when it has been prepared outside the home (de Hooge et al. 2017). Yet, a growing number of the population in developed countries are adopting environmentally-conscious consumption habits (Fraj and Martinez 2006). Both food losses and wastes arise in the preparation of complex food products (FAO 2014a; Parfitt et al. 2010). Discarding the inedible fraction of food ingredients yields a waste stream requiring management or re-utilisation (Kantor et al. 1997); while edible FLW commonly occurs during transformation activities such as further trimming or mixing (Jagtap and Rahimifard 2019).

Underlying the proximate causes of FLW are larger trends in modernised industrial societies and food systems, namely the interconnected processes of industrialisation, urbanisation, economic growth and globalisation, leading to a blending of food cultures and increased complexity in supply chains (Beardsworth and Keil 2003; Thyberg and Tonjes 2016).

Circular Economy frameworks can provide guidance for stakeholders across supply chains to reduce wastes and provide opportunities for productive use (Bocken et al. 2016; Cembalo et al. 2021; Das et al. 2022; Ellen MacArthur Foundation 2021). Circular Economy principles centre on the reduction of wastes through conscientious process and product design, as well as maintaining or increasing the value of by-products and waste streams. Common formulations include the core concepts of reduction, reuse, recycling and recovery (Ellen MacArthur Foundation 2013; Kirchherr et al. 2023), while additional principles include remanufacturing, repairing and refurbishing, as well as product design to facilitate such processes (Buren et al. 2016; Potting et al. 2017). The application of Circular Economy principles results in the narrowing of material flows through waste reduction, closing of flows through collective recirculation actions, and lengthening of flows through increasing the functional value of products (Bocken et al. 2016); resulting in an overarching regenerative production and consumption system (Geissdoerfer et al. 2017). Within the food system, Circular Economy practices map onto the Food Waste Hierarchy, wherein prevention and redistribution of wastes are preferred, followed by the recycling or recovery of nutrients and energy (Moult et al. 2018; Slorach et al. 2019; Teigiserova et al. 2020). Combined emphasis on the Waste Hierarchy and Circular Economy principles is a key part of contemporary legislative packages, such as the UK's Circular Economy Package and the EU's "Closing the loop – An EU action plan for the Circular Economy" (DEFRA 2020, 202; European Commission 2015). Sustainable Development is a key aim of the Circular Economy movement (Ghisellini et al. 2016; Kirchherr et al. 2023), achieved through the decoupling of socio-economic prosperity from environmental degradation, thus enabling cleaner production and consumption systems and contributing to specific goals such as *SDG 12.3—Reduction of food losses and wastes* (Ellen MacArthur Foundation 2013; Ke et al. 2022; Rabbi and Amin 2024).

As well as arising due to internal characteristics of value chain stages, FLW also arises in their interfaces (Mena et al. 2011), and as a result of chains of causation originating in different stages (Raak et al. 2017). Thus, systems approaches, which embrace complexity and attempt to account for the perspectives and conflicts between different stakeholders (Gates et al. 2021; Ison 2008), are helpful in the exploration of problem situations within the food system, in order to generate solutions that move towards increased sustainability (Grant et al. 2019; Li and Qiao 2022; Moores et al. 2025) and Circular Economy implementation (Kirchherr et al. 2023).

Within the existing literature, studies focus separately on the generation and drivers of FLW (Gustavsson et al. 2011; Raak

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et al. 2017; Spang et al. 2019), or on its redistribution and valorisation, exploring surpluses (Garrone et al. 2014, 2016), or quantifying and comparing valorisation routes (Garcia-Garcia et al. 2019; Mirabella et al. 2014). The authors are aware of no studies which explore the dynamics of FLW generation, causation, and opportunities for mitigation in food manufacturing companies across the range of Waste Hierarchy and Circular Economy frameworks. Therefore, this research presents a holistic examination of the characteristics, drivers, and solutions for FLW in the food manufacturing sector for the first time, using a case study of a UK food manufacturer. The aim is to identify the systemic factors affecting FLW using diagramming methods, and to discuss opportunities for reduction and utilisation from a Circular Economy perspective; by doing so answering the following research questions:

- What types of FLW occur in food manufacturing companies and what drives its creation?
- How are Circular Economy principles being applied in the reduction and utilisation of FLW?
- How do interpretations of the issue and solutions for FLW vary between different stakeholders in the production system?

The outcomes of this study will be of interest to food manufacturing companies, to policy makers and to consumers regarding the reduction of FLW, as well as to researchers and practitioners seeking to expand the use of diagramming methods in the movement towards sustainable food systems.

2 | Materials and Methods

2.1 | Data Collection

The data collection took place at a food manufacturer based in Leicestershire, UK, specialising in the fresh prepared food market. The company is part of the Champions 12.3 Sustainable Development Initiative (WRI 2024) and WRAP's Food Waste Reduction Roadmap (WRAP 2024) movements, both aligning to halve FLW by 2030. Prior to participant recruitment and data collection, ethical approval was sought from the Brunel University of London Research Ethics Committee (reference 45264-LR-Oct/2023- 47548-2) and granted on 24th October 2023.

Within the literature, the term *food loss* generally describes a decrease in the total post-harvest food material through processing inefficiencies in upstream food supply chain stages, while *food waste* refers to the discarding of edible food by consumers and retailers associated with actor negligence (FAO 2014a), yet definitions and delimitations vary across stakeholders (Hanson et al. 2016; Spang et al. 2019). This work follows Parfitt et al.'s approach of grouping food losses and food wastes into a single category: *food loss and waste, FLW*, creating a conceptual space wherein all types of food material diverted from the intended consumer or at risk of being discarded can be considered, acknowledging that some may indeed go on to feed people through redistribution and secondary markets (Parfitt et al. 2010).

Participants were approached in two waves of recruitment. Managerial level staff were targeted first, before operational-level staff were included, in both cases through introductions through academic collaborators at the organisation. Potential participants were given information about the workshops, which were scheduled during business hours. Participants were provided with information sheets including details of the workshop itinerary, data handling and anonymisation protocol, and consent forms with which they could confirm their participation in the study. Participants were given the option to revoke their participation and/or the use of their data at any point up until the data was anonymised by the researchers.

In the first round of data collection, workshops included manufacturing-focussed managerial staff—"area managers"—whose role oversees production responsibilities; while in the second round of workshops, operational staff—"team leaders"—were included, whose role coordinates operatives engaged in production processes. Both roles hold specific responsibilities relating to individual areas of the manufacturing facility, overseeing and coordinating the specific tasks and processes related to these production areas. A summary of role responsibilities and production areas is shown in Table 1. Workshop groups included mixtures of specialisation areas; this was both as a result of practical considerations requiring that key production areas were left with adequate staff coverage, and to

TABLE 1 | Description of role responsibilities and production areas included in the 35 participants involved in the study.

Area managers	Team leaders
• Organising and co-ordinating food production teams • Monitoring performance and driving production against business targets • Overseeing of health and safety protocols and practice within production areas • Liaising with other business areas overlapping with production processes	• Organisation of staffing rotation within area-specific teams • Conducting performance reviews, coaching and training • Supporting managerial staff in team performance reviews and health and safety adherence
Production areas	
• Ingredient intake • Storage • Ingredient preparation	• Production lines • Despatch • Specialist products

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include knowledge from all stages relevant to the manufacturing process.

A total number of 35 participants took part in the study, which included 24 area managers and 11 team leaders. Initial coding and thematic analysis stages, described in more detail below, were conducted between rounds of workshops, allowing for the identification of thematic saturation. Thematic saturation was determined when no new codes were generated in new workshop datasets, indicating the dataset was comprehensive with regard to the diversity of participant experiences (Johnson et al. 2020), with no further workshops being organised after this point. Similar studies have included sample sizes ranging from 15 to 36 (Cristancho and Fenwick 2015; Siles et al. 2020; West et al. 2021; Wyatt et al. 2023), with some qualitative studies finding sample sizes as low as 12–20 can be adequate for saturation (Braun and Clarke 2006; Bryman 2012). Focus groups took place in training and meeting spaces within the manufacturer's sites over three site visits between October 2024 and June 2025. Focus groups were assigned alphabetic labels from A to G for the purposes of analysis, with groups A to E including managerial level staff and F and G including operational staff.

2.2 | Protocol

Rich Picture Building (RPB) is a diagrammatic and discursive process wherein individuals draw figurative responses to a prompt (Bell et al. 2016). RPB can be undertaken individually, but when conducted in groups, drawing takes place within the context of a collective discussion (Berg 2015). Tapping into both visual–spatial and audio-sequential cognitive modes (Bell and Morse 2013a), creative thought is encouraged, leading to the drawing out of perspectives that may otherwise lay uncovered (Kado et al. 2023).

Diagramming or mapping approaches aid in the exploration of individuals' cognitive processes (Huff 1990) and in the identification of problem situations and solution generation (Mena et al. 2011; Scavarda et al. 2006). Rich Pictures have arisen as a useful tool in the educement of stakeholder perspectives, typically conducted in small focus groups (Berg 2015; Kado et al. 2023). The technique has variously been applied within the sustainable development movement (Bell and Morse 2013b; Grant et al. 2019); healthcare (Bood et al. 2019); data security (Siles et al. 2020); and tourism sectors (Wyatt et al. 2023), in addition to its long history within the Soft Systems Methodology approach for action research (Checkland 2000; Lewis 1992). When combined with thematic analysis protocols, RPB allows for the co-creation of shared cognitive models that can be systematically interpreted yielding insight into complex problem situations (Bell and Morse 2013a; Carney 1994), aiding both the generation of knowledge and identifying actions for improvement (Avison et al. 2017; Checkland and Poulter 2006).

This study uses the RPB method to capture perspectives on FLW within the case study manufacturing company.

Participants were asked to respond to the following prompt in the RPB activity: *What food waste do you come into contact with in your role, team, and in the wider business? Why does this food waste occur? And what might be the barriers and enablers to reducing or making better use of it?* This prompt was selected to provide responses enabling the overall analysis to address the research questions detailed in Section 2, using the term *food waste* to accommodate participant familiarity and prevalent industrial use.

Participants were shown examples of Rich Pictures from other work and given verbal instruction in the use of various elements in drawing—such as arrows to show interconnectivity, symbols to represent objects, people, concepts, and the use of metaphor. Participants were encouraged not to worry about artistic value and focus instead on capturing all the different elements that they could think of in response to the prompt and that came up during discussion. Instruction material discussed the value of visual methods, encouraging participants to engage with the drawing process as much as possible, with written responses discouraged.

After the introductory material, participants were offered 10 min of individual work to try out the diagramming method and to consider their personal responses to the prompt. Then, participants were invited to form groups of 4–6 people, a size recommended by the literature (Bell and Morse 2013a; Berg 2015; Gisby et al. 2023), and were given 30 min to craft a group response on flipchart paper using colour pens and sticky notes. Participants were encouraged to help all group members engage, with two facilitators wandering the room prompting any of those who seemed to be struggling with the activity (Berg 2015).

Once the drawing section was concluded, a plenary allowed for nominated individuals from each group to talk through their response to the wider group of participants and facilitators. Verbal plenaries were recorded to enable the meaning of each drawn element to be retrieved during later analysis and interpretation by the authors.

2.3 | Analysis

This study uses thematic analysis to search across the Rich Pictures and verbal descriptions in order to identify repeated patterns of meaning in response to the research questions (Braun and Clarke 2006). Analysis was undertaken in an inductive mode, wherein no fixed theoretical framing was imposed on the data set, as this ensures identified themes and interpretation derive directly from the participants' responses (Patton 2015).

Coding and thematic analysis were undertaken by the primary author, with secondary authors providing validation of the analysis and interpretation. The Rich Pictures and audio transcripts were personally digitised and transcribed to enable familiarisation with the data, with preliminary impressions captured. The content of Rich Pictures was then coded first, with audio transcripts serving to validate the author's reading of the visual elements. Carney's (1994) method of art criticism was also applied to analyse the use of colour, line, and emphasis in order to supplement the images with emotive context and evaluate the group's engagement with the process, as recommended by (Bell and Morse 2013a). Both semantic and latent codes were generated, capturing both explicit and underlying responses. The audio

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transcripts were then coded line by line to capture any remarks that were not included in the Rich Pictures themselves. See Tables S1 and S2 in the Supporting Information for summaries of the critical visual analysis and Table S3 for examples of verbal data and codes.

Initial codes were generated with regard to the three main areas participants were asked to respond to: the types, drivers, and potential solutions for FLW across both drawn and verbal data items, with responses then clustered by similarity to generate potential themes linking FLW types to drivers, and drivers to solutions. These were then reviewed for validity and separateness to produce a thematic map based on key themes and sub-themes, and were shared with the secondary authors through presentation and discussion, acting in the role of 'critical friends' to validate and verify that the final themes were complete and sufficiently backed by the raw data, and that assumptions and approach were made explicit in the interpretation and reporting (Braun and Clarke 2006; Gibbs 2007). Initial coding took place in between workshop rounds, allowing for the establishment of data saturation when no new codes were created from new workshop data (Johnson et al. 2020). Further, thematic consistency across participant groups was reviewed through visually mapping instances of themes arising and supporting codes in group responses pertaining to types, drivers, and solutions for FLW. In addition, responses from the participant role-groupings (managerial and operational staff) were similarly compared to identify similarities and differences between stakeholder perspectives. In a final analysis stage identified solutions for FLW prevention and reduction were mapped to a common Circular Economy conceptual framework (Ellen MacArthur Foundation 2013) to understand the applicability of circularity to the FLW mitigation efforts in place at the company and wider sector.

3 | Results

This section presents the participants' responses to the prompts, while later discussion explores their implications in relation to the research questions. All confidential information, for example company figures or supplier details, has been removed with underlying meaning in relation to the research questions retained. Images of the Rich Pictures were taken at the end of each workshop, and are displayed in Figure 1. In the subsequent figures in this section, individual elements from these Rich Pictures have been isolated and collated to illustrate key themes arising in the responses.

3.1 | Types of FLW Arisings

In the drawn and spoken responses to the prompts, participants reported a variety in types of FLW arising in the manufacturing facility, with all stages—including stock management, ingredient preparation, product assembly, and goods-out processes—involved. Following is a description of the main FLW processes associated with the sandwich production operation.

3.1.1 | Processing Trimming

Ingredient offcuts and trimmings arise when ingredient parts are removed during routine preparation activities; tending to be

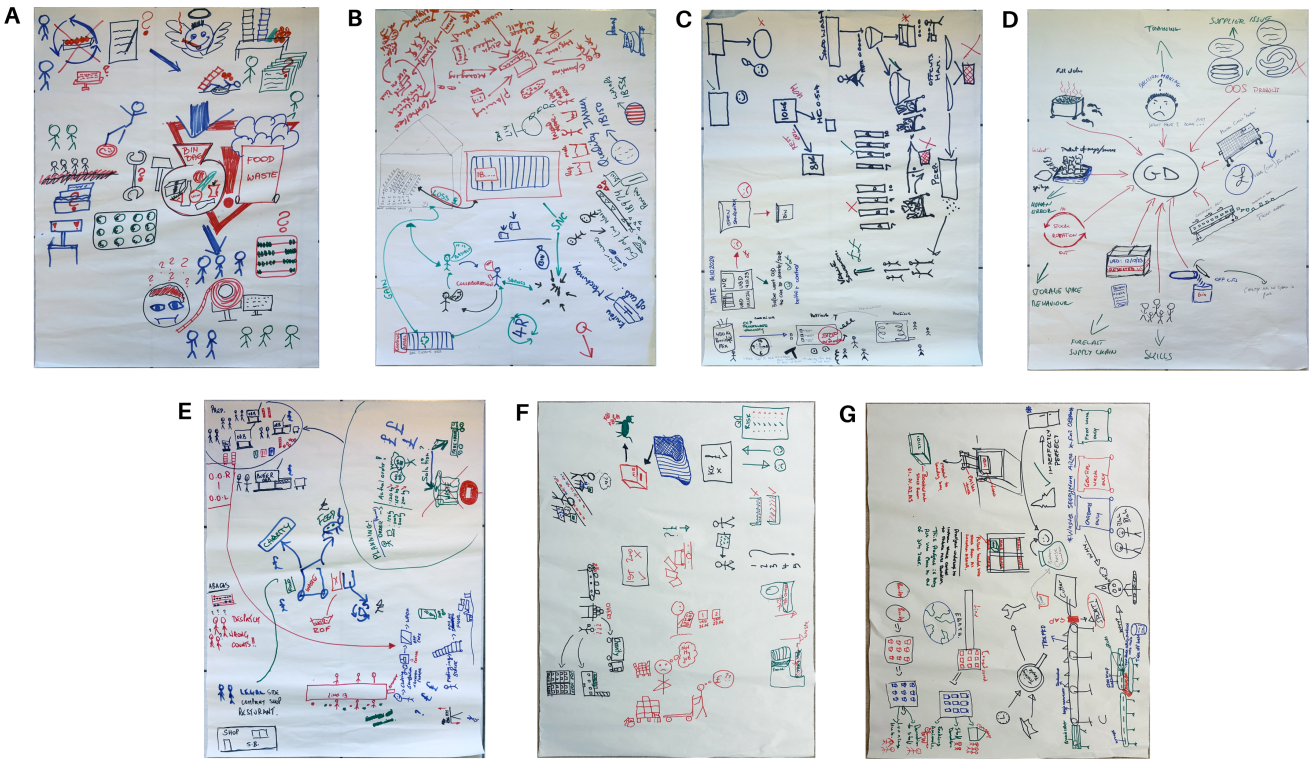


FIGURE 1 | Rich Pictures created by the seven groups in response to asking food manufacturing managerial (A–E) and operational (F and G) employees about the types, drivers, and opportunities for mitigation of FLW in their employment context.

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edible portions of raw ingredient removed to meet the visual or shape requirement of the final product or intermediate processing stages. Individual instances mentioned in responses included the proteins ham, salami, chorizo (Figure 2, left and centre); and bread heels (Figure 2, right), which are known as a major source of FLW in the site, given that each loaf of bread includes 15–20 usable slices and two ends not used for production. Ingredient preparation offcuts are collected as part of the preparation activity for later disposal or management.

3.1.2 | Processing Spillages

Some whole ingredient parts and part-assembled products are lost as spillages during preparation and assembly activities (Figure 3). These include ingredients that are light and susceptible to mishandling such as salad leaves and grated cheese, as well as sauces (Figure 3, centre), other ingredients and whole sandwiches (Figure 3, right). After a spillage occurs, ingredients or products usually fall into collection bins positioned in high-risk areas or otherwise fall directly to the floor where they are collected as part of continuous clean-up activities. Small, repeated spillages can accumulate into large volumes: "the most important part we get [in one area] is cheese waterfall - where we get too much cheese wasted at the end of shift. Last one, two weeks, we trying to weigh it up, it was [a significant amount] on cheese waterfall only." Reporting similar concern at the volume, one participant stated they were conducting "day by day tracking as well so have [how] many kilos we are wasting in that cheese waterfall."

3.1.3 | Accidents

In some cases, larger batches of ingredients are spilled during transit accidents (Figure 4). Participants reported instances of pallets of mayonnaise, tomatoes, or more expensive proteins being broken open or falling to the floor. Large accidents represent significant losses of financial value and embodied labour and can lead to production delays and potential wastes elsewhere: "You lose a stack, and that is so costly because it's not just the cost of that, it's the labour that went into that and then it's the change because they can't possibly make the product they think they're going to make." As production plans must be adjusted to match the available ingredients, effects ripple out into other areas of the facility. A sense of frustration at these occurrences is present in the associated drawings (Figure 4, right) and verbal descriptions. In some additional cases, assembled products are also discarded as possibly contaminated following entry to the goods-out area (an area requiring less intensive hygiene control) in an accidental state of incomplete sealing.

3.1.4 | End-of-Life and Near-End-of-Life

Some ingredients and whole products are discarded after reaching their end of safe life before they can be used (Figure 5). Ingredient shelf-lives are declared by suppliers upon receipt of goods into the facility, while an agreed minimum shelf-life of products sent out to clients is set in contractual agreements. Transformations and preparation activities, such as defrosting, chopping, slicing, or opening packets, change the useable shelf-life of component ingredients while the finished products have consumer-communicated use-by dates printed on packaging. The shelf-lives of prepared components and final products are set and regularly updated supported by microbial and sensory testing undertaken by the manufacturer while all components must have adequate safe shelf-life remaining if they are to be assembled into a final product. Given that ingredients that are near or at the end of their shelf-life cannot be made into products, this is a significant source of FLW reported by participants, occurring in storage areas (Figure 5, right), preparation areas (Figure 5, left), as well as goods-out areas. Larger batches of ingredient or assembled products nearing end-of-life and unlikely to be used

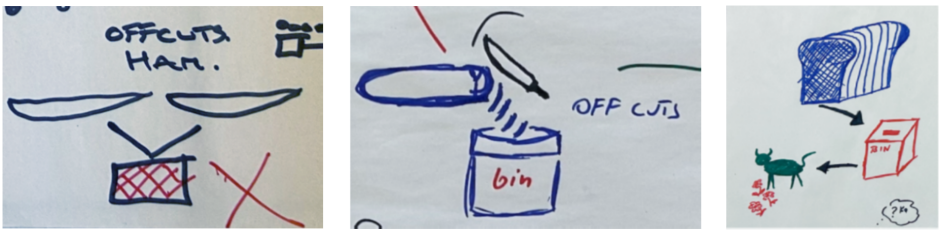


FIGURE 2 | Trimming or preparation process leading to ingredient offcuts. Left and Centre: Group C and D illustrate trimmed ham slices being discarded into a bin. Right: Group F illustrates broad loaf end slices being first discarded then used as animal feed.

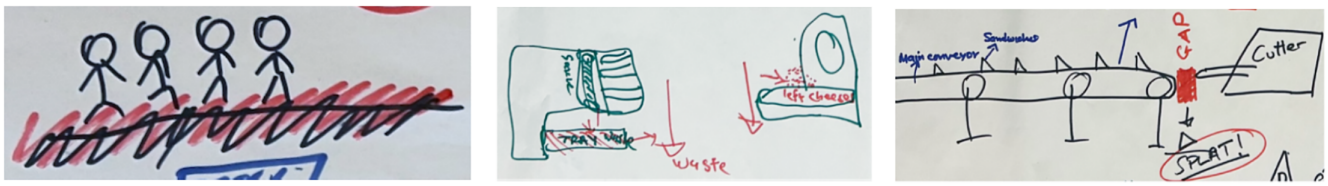


FIGURE 3 | Forms of spillages experienced in production processes. Left: Messy floor beneath a production line (Group A). Centre: Sauce droplets and cheese fragments escape from ingredient depositors (Group F). Right: Sandwiches fall into a gap between conveyor belt and cutting machine inlet (Group G).

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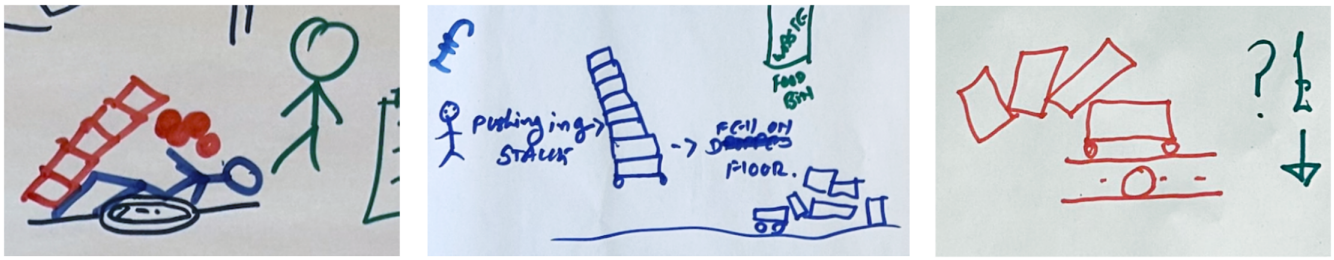


FIGURE 4 | Larger accidents and ingredient losses occurring in production. Left: A stack of ingredient boxes falls onto an operative after catching on a drain (Group A). Centre: An overladen stack falls over after being pushed over uneven flooring (Group E). Right: A stack falls after being pushed over a drain, with monetary loss illustrated (Group F).



FIGURE 5 | Surplus components reaching end of life. Left: Ingredients are left in intermediate storage after stock rotation processes are ignored (Group A). Right: Ingredient batch arrives into the facility already past its use-by-date (Group D).

are referred to as surpluses or "overs", and are generally managed proactively before shelf-life is fully exceeded. In some cases, evidence of spoilage can also occur while a component is within its shelf-life, and affected components are caught in quality control processes.

3.1.5 | Out of Specification

Ingredients and products can also go unused after falling short of visual or other sensory standards. Participants report this occurring in the goods-in area, where ingredients arrive in a state below what is expected of supplier deliveries (Figure 6, right); in the preparation and assembly areas—including both prepared ingredients and part-assembled sandwiches (Figure 6, centre); and in the goods-out area—including assembled, sealed sandwiches deemed visually unacceptable for sale to the primary client (Figure 6, left). Visual and sensory standards are agreed with clients during product development, and regular monitoring and recipe reviews ensure such standards are attained consistently during preparation and production activities. Quality control checks ensure any components or products falling below the standards are not shipped out, and aid in identifying any repeating issues. Some newer products were reported as being particularly susceptible to quality failures, such as large platters and paninis. Other related FLW arisings include components that are damaged and, while not below explicit product standards, are in a state where further processing is not possible—such as broken cheese blocks which cannot be fed into graters or slicers.

3.2 | Drivers of FLW

Proximate causes for FLW being disposed or requiring management as reported by participant fall into two broad categories: items that are edible but not deemed usable in their current state; and items that are contaminated, unsafe or otherwise inedible. However, a number of underlying factors cause products and components to fall into these final states.

3.2.1 | Equipment Failure

Equipment failure can lead to a number of FLW types. Misaligned conveyers and depositors can lead to minor spillages (Figure 3, right), while some particular machinery such as cutters or packaging-sealers rely on parts susceptible to wear and

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FIGURE 6 | Instances of products or ingredients falling outside of retailer or supplier specifications. Left: An ingredient lies on top of a closed sandwich (Group A). Centre: Bagged bread loaves become deformed after being overladen in transport trollies (Group C). Right: Cucumbers with too much curvature fall outside the specifications agreed with suppliers (Group D).

requiring maintenance. Continued use can lead to improper slicing, sealing, or leaking, resulting in a visual or sensory standard impingement, and thus arising as an out-of-specification component at quality control stages. Improper sealing can also lead to a product written off as possibly contaminated if it enters into a less intensely controlled area of the facility in an open state. Larger accidents can also occur when a single piece of machinery completely stops, leading to line halts that can lead to component damage, spills, or spoilage if not conducted effectively. Random machine errors are rare, and machinery-related FLW is generally underlined by improper set-up or lack of maintenance.

3.2.2 | Human Error and Mishandling

Participants reported immediate human error as a significant driver of FLW across spillages, accidents, and out-of-specification categories. This factor was also associated with some of the most overt displays of emotional content in the drawings. Improperly laying ingredients was reported as driving regular losses through spillage, while mis-filled sandwiches can also be rejected at quality control. This in turn was interpreted as being either due to insufficient skill or familiarity with sandwich recipes or improper level of concentration on the task—with the ingredient weighing step highlighted as a key source (Figure 7). Use of question marks in drawings and tone of voice in plenaries demonstrated that frustration and confusion were present as participants attempted to pin down the route of this issue: "If we look at why we do that, then it's we're not skilled enough, or maybe we're distracted at work, or we're talking with people … so we're not putting the ingredient in the sandwich properly, because we're not focussing." On the other hand, some participants explored how different ingredient weighing practices can lead to larger or smaller deposits, illustrating that technique is also at play, rather than simply a lack of focus: "If we [after picking up a load] drop [a little] down we hit the highest tolerance we could possibly have for the product, whereas if we [start small and] pick up a little bit more, you reach the bottom tolerance first."

Ingredient transit was highlighted as a key area for human mistakes to occur: ingredient stack collapse was noted many times, significant also due to the quantity of FLW that can occur in one incident: "We have instance where we got stacks going over, which is all just a complete waste. And everything - as you look at it – it's like, everything you lose, we'll lose money in there, we'll lose money in prep." Participants reported a sense of inevitability caused by the conditions leading to the accidents: "There's always

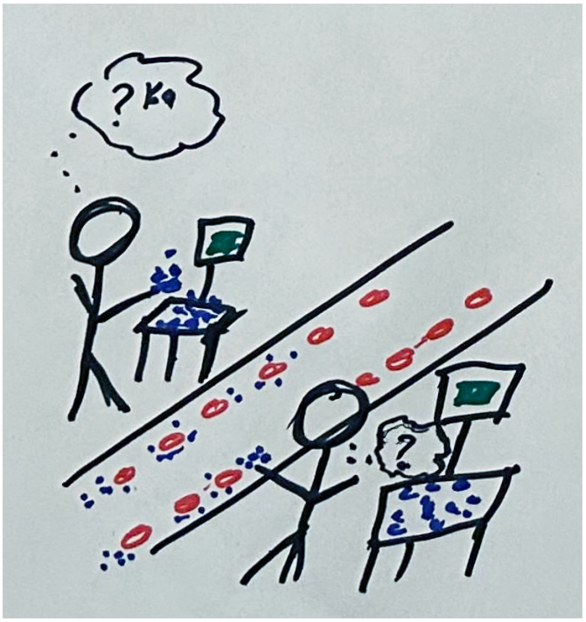


FIGURE 7 | Human error or lack of experience leads to ingredient over-spill during weighing-out and depositing of ingredients (blue) onto partially assembled sandwiches (red) (Group F).

the risk of going over the drains, as the prep guys know"—as well as a sense of exasperation at the loss caused by one small lack of judgement: "Something we - again we didn't mention is, we stack stuff up, we get it nice and neat, we put effort to get it into the right part of the bakery. And then we don't take care when we wheel it out there." Operatives involved in transfer operations do not always understand the significance of potential losses, highlighting a difference in perspective between operational and management level staff as illustrated in Figure 8: "Not saying it happens all the time but if it does happen it affects the food waste. One man here who wasn't very careful who hit the pallet - destroyed one box, dropped another box, and like it's been said before, people don't realise the value in pounds. […] he doesn't realise how much it costs to the business, for him it might be just one box but for business it might be few hundred pounds."

3.2.3 | Errors in Communication and Coordination Systems

Stock management and booking out systems are not always correctly adhered to, leading to some components needlessly

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reaching their end-of-life or surpluses being generated (Figure 9). A commonly cited area was in storage retrieval activities: a First-In-First-Out system instructs operatives to collect the ingredient batch with the least shelf-life left, yet in many cases, this instruction is overridden and the operative collects a different batch, likely due to it being easier to access: "We get things in prep where you get out of rotation, so where people will just batch out the lines, and they don't look at the dates or the tickets and they'll take the nearest one and put it in." As a mitigating process, stock status reports are run regularly, highlighting component batches that are nearing end of shelf-life which can then be expedited for production or used in a different way. However, in some cases, such reports are not given sufficient attention, illustrating that some disregard for due process can underlie surpluses and end-of-life FLW.

Further, surpluses can also be generated during preparation and assembly stages. When allocating out components for production runs, extra components are sometimes booked out to cover higher-than expected usage rates or common preparation issues. If this is not correctly reported, FLW can be hidden from monitoring systems and consistent underperformance persists.

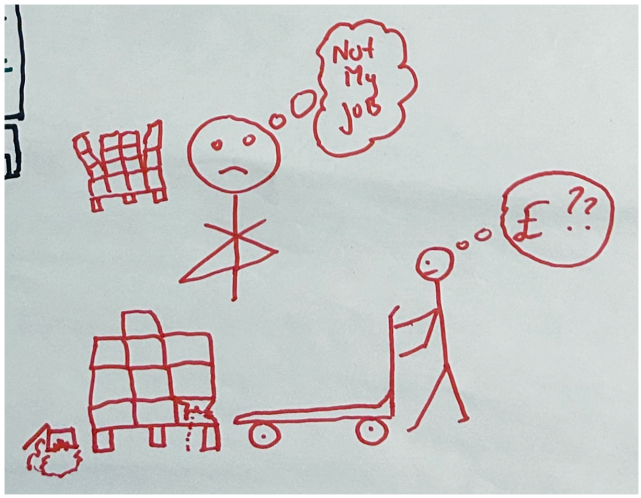


FIGURE 8 | Attitudes indicating a lack of accountability and ignorance of ingredient cost leading to accidents and spills (Group F).

In addition, production counts are taken in order to correctly stop a run when the correct amount of product has been made. Two counts are taken: one at the front of line where the first ingredient (bread) is laid out, and one at the back of the line where sandwiches are assembled into pallets ready for despatch. Seemingly, counts can vary between operators at each position, leading to surplus components being loaded onto lines, or in some cases surplus products reaching final assembly. Some preparation tasks appear to be duplicated in production planning schemes, leading to regular surpluses of prepared components. Any surpluses not proactively managed become at risk of reaching end-of-life and requiring disposal. Finally, some participants reported clean-down operations being started before part-used batches of ingredient are examined, labelled, and booked back into storage areas for later re-use, leading to unnecessary disposal of usable components.

3.2.4 | Supply Chain and Product Specification

FLW is generated at the interface with the upstream supply chain and with the downstream supply chain, ordering, and quality control processes. Generally, the majority of ingredients arrive at the manufacturing facility in an edible state; however, some ingredients cannot be procured in a directly usable format and require specific trimming and cutting to fit with the product design. A large source of edible but unused components is bread loaf ends, which are not currently used in any products. Ends are kept in the loaf for structure during transit, and their removal by the supplier would also increase labour and waste management costs in their operation; therefore, the impetus to manage or dispose of them falls to the manufacturer.

Surplus components also arise due to supply chain factors. Estimated order volumes are received from clients around a week in advance, while actual order volumes are confirmed around 48 h before receipt is due. For some ingredients with longer lead times, the manufacturer predicts how much to order in based on annual order fluctuations. Stock inflow and outflow must also be balanced with storage space, with some possibility to freeze excess ingredients that can withstand the process. When retailer orders fall short of original forecasts, this can lead to surpluses of raw and prepared ingredients. In addition, some suppliers set

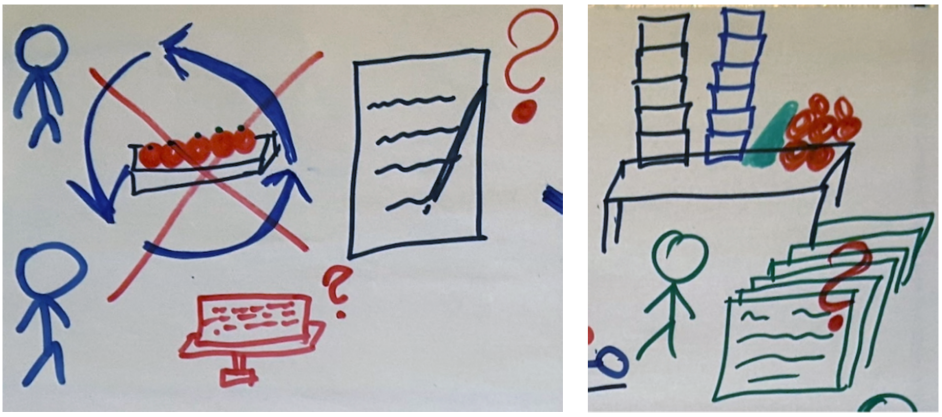


FIGURE 9 | Confusion and frustration as stock rotation and booking out systems are not followed correctly, leading to surplus stock left in storage (Group A).

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minimum order quantities higher than the average usage rate in the manufacturer, leading to expiry of some specialised ingredients. Changes in product formulation can also lead to redundant ingredients being left in storage. Any surplus or redundant components cannot be returned to suppliers or passed on to clients, and therefore are at risk of reaching end-of-life if unmanaged by the manufacturer.

3.3 | Solutions, Barriers and Enablers Prevention and Utilisation

Following on from the drivers of FLW identified by participants, solutions and opportunities for improvement were reported, drawing from existing management practices, schemes in development and partial implementation, and ideas that arose out of discussion or that had yet to be implemented in the business.

3.3.1 | Responding to FLW Arisings

The established practices undertaken by FLW management teams start with effective segregation into separate waste routes: a pure bread-end stream, a mixed FLW stream, safe routes for other surpluses and edible components, and a stream for non-food items, treated separately and sent to recycling and energy recovery operations.

Participants highlighted that a proportion of the currently disposed ingredients is suitable for internal re-use, were the correct processes to be put in place. This includes setting up capture trays to recirculate appropriate ingredients such as grated cheese. Further, new product formulations could be developed to utilise preparation offcuts, such as sandwiches made of ham chunks (rather than slices). Additionally, existing processes have been set up to distribute surplus and out-of-specification components and products to staff, via the facility's in-house canteen. Similar external redistribution efforts are in place, with working relationships in place with local food banks and secondary markets. Generally, these are called on for the distribution of larger batches of redundant or nearing end-of-life stock, but novel arrangements such as the donation of "crust loaves" made up of unused bread heels are in development. Collectively these novel solutions represent a widening and intensification of FLW utilisation strategies, addressing the need to find valuable processes to make best use of unwanted or unsafe food material after it arises.

Some participants discussed legal restrictions around redistribution routes and cited a sense of frustration accordingly: "Some of it can go to charity… Or, to the restaurant. There are legal obligations there, there are walls and hurdles to go through to make that happen." New routes for donation or sale of edible components to processors to formulate into new products are also under development, again with bread ends—examples include the production of breadcrumbs or its use in brewing to replace virgin barley—while redistribution to animal feed has been a traditional FLW valorisation route for bread ends. For mixed FLW streams, the majority of the material is managed via anaerobic digestion, as having any meat content negates redistribution to people or animals. Anaerobic digestion produces electricity to the UK energy grid and a digestate that can be used as fertiliser. Participants highlighted a traditional attitude of conservatism around FLW management routes is changing: "We are trying to promote that culture where, we're trying to get people to start asking the questions: where can it go, who can take it, what can we do with it"—with possibilities illustrated in Figure 10.

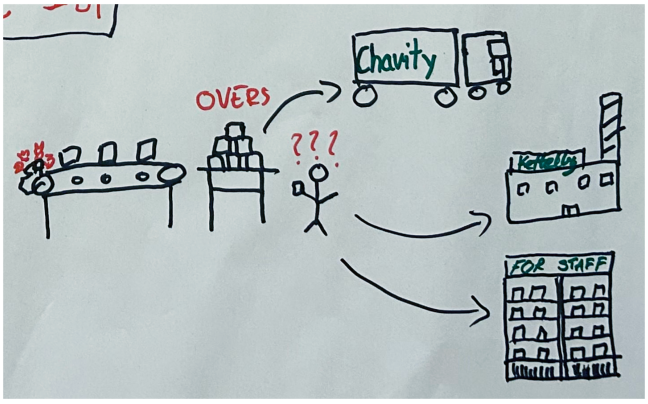


FIGURE 10 | Surplus stock arising during production is redistributed to charity initiatives, other manufacturing sites within the company, or in the staff canteen, overseen by a critical staff member (Group F).

3.3.2 | Acting Creatively

Participants also highlighted that preventing FLW from arising is extremely beneficial to the business, stating "If we get it right first time, that's amazing and we should get it right first time. If for any reason, we go to second time, then we've incurred a cost, of ingredients, of labour." FLW prevention strategies were suggested for many of the identified drivers of FLW, examples of which are illustrated in Figure 11.

Setting up and ensuring the proper use of information and communication systems was a key theme that emerged. Better use of existing forecasting and order adjusting processes, end-of-life alert systems, and stock rotation systems was highlighted as key to preventing surpluses from arising and reaching end-of-life before a use can be found. New processes to ensure the correct ingredient amounts are booked out for production runs would also prevent assembly over-utilisation and spillages. Participants also highlighted a need for better communication of the largest sources of FLW, underpinned by reliable and representative monitoring systems: "If they tell us what are my five biggest areas are, maybe we can concentrate on those - that might be the five biggest by monetary value, or the five most frequently occurring." Relating FLW volumes to price was also highlighted as likely to have an impact on operative behaviours and attitudes: "We talk about kilos lost, but I think for most people downstairs [on the assembly floor] it would make more impact if we talked about pounds and pence lost." Similarly: "It's been said before, people don't realise the value in pounds… [a figure drawn in Figure 8] doesn't realise how much it costs to the business, for him it might be just one box but for business it might be few hundred pounds."

The redesign of spaces, physical processes, and recipes was highlighted as a way to prevent a number of FLW types. Redesign of

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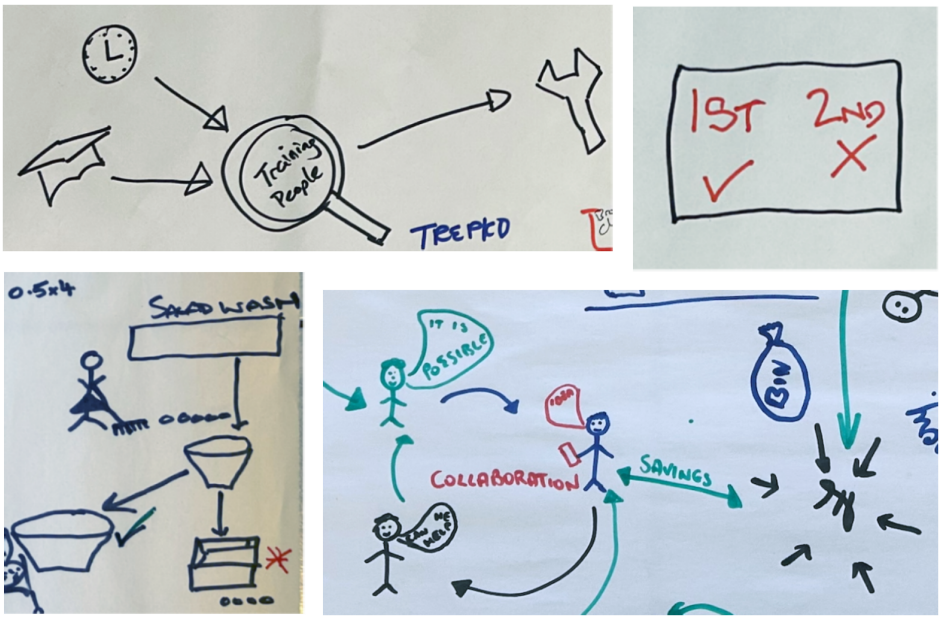


FIGURE 11 | A variety of FLW prevention schemes. Upper left: Time dedicated to training leads to more highly-skilled operatives (Group G). Upper right: A desired culture of preventing mistakes and getting things "right first time" (Group F). Lower left: Equipment redesign matches funnelling equipment with final receptacles, leading to less spillage onto the floor (Group C). Lower right: Inspired and empowered staff members seeking collaboration with other employees for problem-solving creates a virtuous cycle leading to cost savings (Group B).

equipment set-up and increased maintenance of existing machinery were suggested as ways to avoid routine spillages, while participants acknowledged the financial investment required. Schemes that are cost-effective were cited as more likely to gain traction within decision-making environments. Redesign projects in the storage area were reported as being underway to make stock rotation systems easier to follow, while new processes for sealing half-used ingredient bags were postulated, both as effective ways to combat early end-of-life FLW. Consolidation of similar ingredients along different product lines was also discussed as a way to reduce the expiry of components whose usage rates are lower than minimum supply quantities.

Staff training and cultural shifts were suggested to increase skills and prevent human error, particularly around machinery operation, following established procedures, and laying ingredients accurately. It was noted that devoting time to peer-to-peer learning could help upskill more junior team members: "What can we do to help prevent that is get the people who are experienced, get the time and put that into training people". At the same time, fostering an attitude of care for ingredients and products was also suggested as a way to combat accidents and component damage. Mindful pauses are taught to staff and encouraged through signage as a way to ensure correct hygiene practices are followed, an approach that could also be applied for FLW prevention.

Coordination and management structures were highlighted as a core enabler for FLW prevention. Within the business, clarifying the responsibility for FLW reduction would help motivate individuals to implement correct behaviours. In some teams, such an attitude is already emerging, with collaborative working groups set up to address individual problems and develop solutions—the creation of the new sealing process was highlighted as a recent example. The identification of cost-saving projects was also cited



FIGURE 12 | Recognising an overarching motivation for FLW reduction: Stewardship of the planet's resources (Group G).

as a path to increase resource allocation within the business; while another important factor is the activation of individuals' ethical motivation. Giving resources to particularly motivated people to spearhead projects is a clear enabler, while emphasising the environmental benefits of FLW reduction (Figure 12) may help to foster this spirit in the larger workforce. Some participants cite that a spirit of care and helpfulness is present, recognising that the benefits of FLW reduction will be felt in all teams.

Within the wider supply chain, the renegotiation of supplier and client agreements was highlighted by participants as a way to reduce multiple FLW categories. With upstream suppliers,

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addressing minimum order quantities and inflexibility around changing order sizes to match demand would help to prevent surpluses arising. In addition, setting higher component standards for suppliers could reduce the amount that the manufacturer has to dispose of or redistribute, and incentivise suppliers to find alternative markets or undertake processing improvements. On the client side, relaxing final product visual standards would help to avoid the disposal of out-of-specification products and components which are otherwise edible and in line with other sensory requirements.

4 | Discussion

Responses from the participants to the workshop prompts illustrated that FLW is generated due to a large number of independent and interrelating factors, mapped graphically in Figure 13. Feeding into the five main types of FLW, groups were able to bring together expertise from different areas of the manufacturing facility to present coherent narratives on FLW generation. Potential solutions were suggested for all driving activities associated with FLW, demonstrating considerate engagement with the construction of FLW prevention and utilisation strategies and application of Circular Economy principles.

4.1 | Unwanted and Unsafe Food

With regard to the types of FLW occurring in the facility, ingredients and finished products arise as FLW into management processes as a result of two major themes: the components are unwanted, or the components are unsafe to eat. Classifying the FLW types into the two themes aids both in the identification of showing the chain of causality of FLW drivers and the selection of relevant management and utilisation options. Essentially

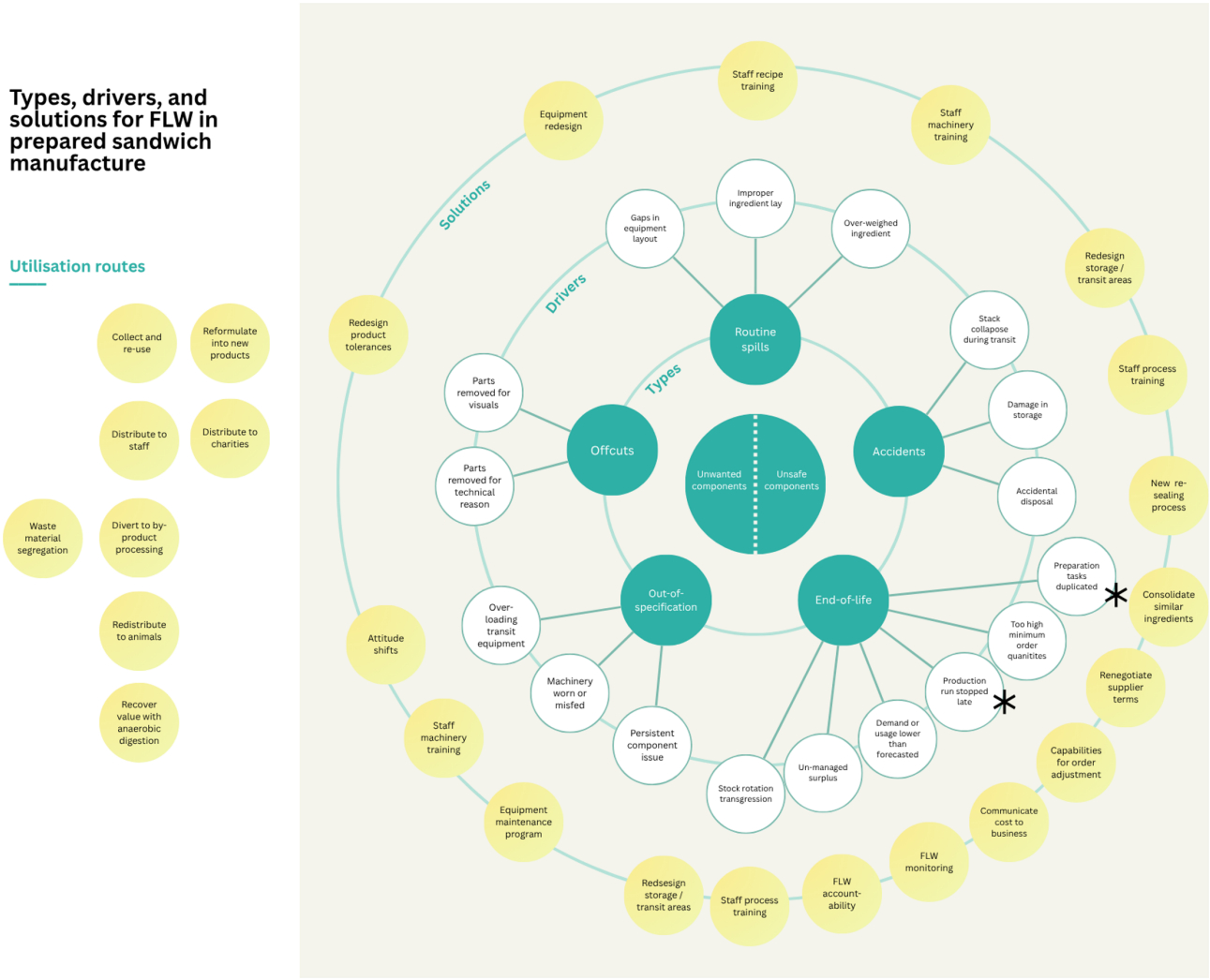


FIGURE 13 | The interrelation of types, drivers, and solutions for FLW, as reported by workshop participants and grouped into main themes. Food material becomes either unwanted to unsafe, as in the five main types of FLW (inner green nodes); caused by the drivers including equipment, human error, internal co-ordination, and supply chain processes (inner white nodes). Solutions identified (gold nodes) are grouped into post hoc collection and utilisation activities (left-hand columns) and proactive prevention strategies conceptualised to counteract or address individual drivers (outer ring). Causal connections are illustrated with dark green connectors, while prevention strategies are linked to the drivers they address with dashed yellow connectors.

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all food material handled in the facility is subject to some FLW, with the five major categories mapped out in Figure 13. Buzby and Hyman (2012) group their survey of commercial and institutional FLW into similar categories, adding damage to packaging and emphasising the over-preparation and spoilage of seasonal holiday food types. Spang et al. (2019) and Mena et al. (2011) also suggest over-forecasted and spoiled products and ingredients are a significant FLW type in their reviews of global and European FLW.

Drivers for FLW revealed by participants centred around equipment errors, human mistakes, failures in coordination and communication systems, and supply chain and product technical factors, indicating a range of interconnected factors feeding into FLW generation. In a comparable study of a UK ready-meal factory, Jagtap and Rahimifard cited quality standards, processing losses, expiry in storage, over-production, and machine failures as key drivers of FLW, while implementation of an integrated digital FLW tracking system led to a 60% reduction over a 12 month period (Jagtap and Rahimifard 2019). FLW mitigation actions facilitated by the system aligned with those reported by participants in this work, including re-use of ingredients within the facility, donation schemes, renegotiation of supplier minimum order quantities and lead times, closer relationships with clients over order forecasting, training staff in hygiene and allergen protocols, and more regular machinery maintenance and performance monitoring, highlighting a concordance of the FLW drivers faced by complex food product manufacturers.

4.2 | Implementing Circular Economy

With regard to the application of Circular Economy principles in the food manufacturing sector, frameworks offer guidance on the elimination of wastes via prevention and productive utilisation (Ellen MacArthur Foundation 2013), while once a waste stream arises, the Food Waste Hierarchy provides guidance on the most preferential strategies for management (Papargyropoulou et al. 2014). Comparatively, participants provided a richer set of solutions relating to prevention actions, with fewer utilisation options discussed, mirroring the broad range of FLW drivers that such solutions were addressing. Utilisation strategies suggested by participants included a large focus on re-use options, which are most preferable from in Circular Economy and Waste Hierarchy frameworks (Kirchherr et al. 2023; Teigiserova et al. 2020), namely in collection and use or reformulation of uncontaminated spills, and redistribution of safe but unwanted food items to staff, charities, or to animal feed. Animal and human redistribution is well established in the contemporary food supply chain (Garrone et al. 2016; WRAP 2024), relying on supply chain partnerships and digital tools, while significant logistical and legislative barriers are present, with some studies also indicating rebound effects of donation can be significant (Sundin et al. 2022). Re-use strategies in this work included some existing schemes and many in conceptualisation or development phases. Conversely, the company's major existing waste management routes include lower priority strategies: nutrient recovery through anaerobic digestion and energy recovery from incineration of non-food wastes. Material recycling strategies, which include industrial use, by-product processing and bioconversion, were comparatively less explored in participant responses than other Circular Economy and Waste Hierarchy routes. Prior work within fresh prepared food manufacture places mixed FLW sent to anaerobic digestion as the most significant waste stream on a volume basis, at approximately 60% of total FLW (Moores et al. 2026). Impact assessment studies generally consider anaerobic digestion as an emissions-saving management route owing to the production of electricity, heat and digestate fertiliser which can substitute virgin sources (Slorach et al. 2019). Similarly, FLW donation and animal feed processing can lead to significant environmental savings due to the reduction in primary production (Eriksson et al. 2015). Specific performance is heavily dependent on the physical characteristics of the FLW stream and the substituted supply chain (Moult et al. 2018) as well as the sustainability impact categories examined. Anaerobic digestion can often outperform high-priority alternatives such as animal feed in impact categories closely affected by energy production such as greenhouse gas emissions and ionizing radiation; the latter faring better in categories associated with agricultural production and land management (Vandermeersch et al. 2014). Sector-wide estimates in 2014 for the FLW destination mix suggest anaerobic digestion, land-spreading, and incineration with energy recovery are the most common (WRAP 2022), illustrating there are significant gains to be made even within the lower rungs of the waste hierarchy.

At the same time, prior analyses suggest that higher-priority material recycling strategies are of particular relevance to food manufacturers, given the sophistication of existing industrial networks and expertise in food processing activities (Ellen MacArthur Foundation 2015). Industrial symbiosis, wherein by-product and waste material streams are shared between companies and actors to reduce environmental externalities and create value, is recognised as one of the most long-standing industrial movements aligning with Circular Economy principles (Pagotto and Halog 2016; Short et al. 2014). Within the fresh food sector, bread is highlighted as a significant opportunity for material recycling and bioconversion due to its carbohydrate content (Ben Rejeb et al. 2022), with authors reporting novel processes for the production of ethanol (Pietrzak and Kawa-Rygielska 2014), fermented protein products (Brancoli et al. 2021; Sandoval et al. 2024), and additional non-food biochemical products (Ben Rejeb et al. 2022). Some industrial networks exist at present to directly recycle bread wastes into food products, such as in the substitution for malt barley in brewing (Toast Ale Ltd. 2024), and for virgin flour in bakery products (Samray et al. 2019). Mixed FLW presents increased challenges for bioconversion and recycling due to water content, inconsistent composition, and potential for contamination with animal proteins which limits the possibility for recycling within the human food chain (Canali et al. 2017; Muradin et al. 2018). For example, common sandwich ingredients such as cheese, sliced ham, chicken breast, tomatoes and lettuce hold average water contents between 40% and 96%, with bread commonly around 35% (Public Health England 2021). Yet, some conversion routes are reported in the literature (Hafid et al. 2017), including novel conversion processes such as insect larvae production for animal feed (Jagtap et al. 2021) and biofuel production (Hafid et al. 2017).

Waste managers face hurdles when seeking partnerships for material recycling, given the low technology readiness level of many novel conversion pathways (Caldeira et al. 2020). Companies also face costs for capital investment (Kirchherr et al. 2018),

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any additional materials and labour (Hetherington et al. 2024), as well as logistical barriers for fast-spoiling foods (Narisetty et al. 2021; Stevens et al. 2018). Teigiserova et al. (2020) offers a framework for identifying preferential waste streams suitable for bioconversion which can be used for managerial decisions and developing new practices. Supplementing the Waste Hierarchy, the framework focusses on foods components that are inedible by nature or have been rendered inedible from processing, leaving accidental and preventable FLW sources to be targeted with prevention or re-use actions. Verification that Circular Economy initiatives lead to reduced sustainability impacts is tantamount to increasing environmental, social and economic performance (Moores et al. 2025), given the influence of burden shifting and trade-offs between impact categories (Moult et al. 2018; Slorach et al. 2019). Life Cycle Assessment, Material Flow Analysis and other quantification methods provide evaluative methods (Garcia-Garcia et al. 2021; Hanson et al. 2016), while it is important that FLW prevention activities and their evaluations are feasible in terms of labour, cost, and the constraints of equipment and physical spaces (Lévesque et al., 2022), as well as stakeholder expertise (Das et al. 2022).

Regarding the prevention and reduction of FLW at source, participants cited a range of opportunities at various stages of implementation including improved information and communication systems, changes to processes and physical spaces, more intensive staff training, and new management and coordination systems. Nearly all drivers of FLW were addressed by these interventions directly, with increased accountability and monitoring likely to have an impact on remaining drivers such as unmanaged miscellaneous surpluses and software issues. While prevention actions are proscribed in less detail in Circular Economy frameworks, optimising the material efficiency of operations is encouraged. According to one food manufacturing-specific framework, ingredient diversification is highlighted as a possible strategy (Ellen MacArthur Foundation 2021), however, this appears to be at odds with supply chain dynamics regarding order quantities, with participants in this work instead suggesting ingredient and product consolidation as a way to improve material efficiency. A previous study of European supplier-retailer relationships found that when stakeholders increase data-sharing and engage in measuring and clarifying the responsibility of FLW, order forecasting is improved and FLW prevention actions are more deeply embedded in management structures (Mena et al. 2011). Similarly, Garrone et al. suggest measurement, coordination and organisation structures are necessary parts of surplus food management systems, while developing proactive and regular contact with external redistribution organisations is needed for productive alternative use (Garrone et al. 2016). These researchers also mirror the concern for staff training as a key opportunity for process improvements reported by participants in this work. Necessity for staff training has been found to increase during times with greatest market activity due to the intake of seasonal staff members into production teams to meet demand (Mena et al. 2011). Given that the food sector is a common source of employment for seasonal and newly migrated workers (Fernández-Reino and Brindle 2025; McGuinness 2017), it is important that training material is prepared accordingly for individuals of varying proficiency in English or possessing educational qualifications different from those of the host country (Clark and Drinkwater 2008; Davies 2019; Dawson et al. 2018).

4.3 | Internal and External Stakeholders

Within the stakeholders examined in this work, many of the major FLW generation, prevention and utilisation activities were cited by both operational and managerial level staff. The company has been a signatory of the UK Food and Drink Pact (formerly the Courtauld Commitment) to reduce FLW by 50% by 2030 since 2017, and is committed to the Champions 12.3 pledge; appropriately, both operational and managerial staff demonstrated strong awareness and engagement with FLW reduction within the business. Yet, participants mainly responded regarding their own business area, indicating specific knowledge of waste-generating processes may be siloed to each area of the manufacturing facility. Little difference was found between the themes arising from operational and management level staff, indicating that role level did not affect the knowledge or awareness of FLW processes as much as area of responsibility. Not all staff within a business will have equal engagement or interest in FLW reduction (Filimonau and Gherbin 2017). Thus, these factors highlight the need for cross-area collaboration, which was itself alluded to by participants calling for integrated working groups to be set up within the business. At the same time, the adoption of Circular Economy goals into the company management structures is a key enabler to implementation of more circular resource flows (Kirchherr et al. 2018).

Responses from participants showed awareness of the underlying logic behind Circular Economy, prioritising the extraction of nutrients and embodied labour in productive uses, with energy recovery used to avoid landfill and close the resource flow. Thus, though not explicitly labelled in such terms, FLW prevention and utilisation activities are in alignment with Circular Economy principles of narrowing, slowing, and closing resource flows (Bocken et al. 2016). Yet, coordination with external parties remains a significant barrier, and organisations struggle when external partners remain committed to linear or waste-intensive processes (Filimonau and Gherbin 2017). With a significant proportion of the amount of FLW created in the manufacturing stage being ultimately caused by external stakeholders (Moores et al. 2026; Raak et al. 2017), this demonstrates the necessity for collaboration across supply chain stakeholders for further FLW reduction, in addition to the range of internal efficiency improvements targeted by the interventions proposed by the workshop participants.

4.4 | Significance, Novelty and Contribution

The reduction and utilisation of FLW in the manufacturing sector is significant in the UK context given the high share of manufactured and convenience foods in British diets (Monteiro et al. 2018). The UK's market for the preparation of fresh convenience foods in particular is valued at £22.9 billion in 2023, with projections of 30% market growth by 2028 (IDG 2023). Indicative products such as ready-meals show consistent growth in market sizes and above European-average shares, valued at £3.9 billion in 2023 (Jackson and Viehoff 2016; Mintel 2024). Depending on the precise products included, the global market size of fresh and pre-packaged sandwiches is estimated at between $165 and $246 billion USD (Fortune Business Insights 2026; Kelly 2026),

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indicating an enormous potential for impact through resource efficiency interventions.

Prior work has illustrated that FLW rates in representative products are significant: as high as 13% in chicken salad sandwiches (Moores et al. 2026), and in the 5%–8% range for UK convenience food manufacturing companies (Bakkavor 2020; Greencore 2020; Samworth Brothers Ltd. 2020). Within the UK alone, the FLW contribution from the food manufacturing sector is estimated at 1.4 Mt. in 2021 (WRAP 2025). Thus, the identification of solutions for FLW reduction and utilisation presents significant opportunities for and international FLW reduction. Further, with the significant environmental burden of staple fresh prepared food ingredients such as salad items and animal-derived proteins (Espinoza-Orias and Azapagic 2018; Imran et al. 2025), FLW reduction in this sector has significant potential to translate into environmental impact reduction and support broader movements such as Net Zero emissions (Garvey et al. 2021).

This work has provided further empirical evidence for the multitude of FLW types occurring in food manufacturing contexts, including process-related, accidental damage, trimmings, quality and end-of-life arisings. To a range of existing drivers, this work provides new evidence for the relevance of attitude and behavioural factors, and of working relationships with upstream and downstream stakeholders. Meanwhile, this study contributes to the theoretical understanding of Circular Economy application in the food manufacturing sector, by presenting a taxonomy of FLW types arising from a detailed case study. Further, these categories of FLW have been connected with a comprehensive suite of drivers and proposed solutions, for the first time demonstrating the implementation of Circular Economy principles, ranging from reduction and re-use to nutrient and energy recovery, in a holistic case study enabling naturalistic and in-depth analysis. Within the wider discourse, Circular Economy frameworks and Waste Hierarchy guidance advocate for FLW prevention in the first case; however, detailed conceptual understanding of the barriers and enablers for such FLW prevention has been under-studied in the food manufacturing sector. This study goes beyond previous literature to present a detailed case study analysing FLW generation and management holistically, integrating systemic and Circular Economy perspectives. Accordingly, the work has demonstrated that the prevention of FLW, as advocated by Circular Economy and Waste Hierarchy guidance, rests on the implementation of a range of individual actions rather than from a single "silver bullet". Thus, it illustrates that the embedding of Circular Economy principles into management structures is a key enabler to its implementation.

Managerial implications arising from the analysis also evidenced opportunities for further Circular Economy implementation, through a focus on material recycling, tracking and monitoring systems, and the importance of cross-stakeholder working groups, across both organisational departments and with wider supply chain actors. The analysis also demonstrates the efficacy of visual methods in surveying FLW dynamics in organisations with the goal of identifying potential interventions. Broadening into the policy sphere, systemic interventions for FLW reduction as leveraged through policy changes have been shown to be effective in the consumption stage (Reynolds et al. 2019), while in the UK, the opportunities illustrated by whole-supply chain FLW reduction plans have spurred some policy developments (IGD & WRAP 2023). Yet at present, these have seen limited adoption and remain voluntary initiatives (Bradshaw and Wentworth 2024), risking a stifling of their effectiveness in the reduction of FLW and its impacts (Chalak et al. 2018; Chauhan et al. 2021).

4.5 | Limitations

Given that this study involved participants from only the manufacturing sub-sector, conclusions cannot yet be made about the FLW generation and mitigation activities, or specific Circular Economy strategies relevant within other food supply chain stages at present. As well as expanding the knowledge of FLW in other parts of the supply chain, it would be beneficial to understand how the behaviours of manufacturing companies impact the FLW generated in, for example, upstream and downstream stakeholders, to understand the other part of the picture.

In addition, this study examined a single business only, and cannot claim that the set of drivers and solutions are exhaustive or immediately generalisable to the wider food industry. At the same time, there is significant agreement in the main types of FLW and drivers reported in this work with other studies examining alternate product systems, supply chain stages, and regions (see Jagtap and Rahimifard 2019; Mena et al. 2011; Raak et al. 2017). Similarly, general stages of inventory management, processing, assembly, packaging and waste management are common across the industry (Adams et al. 2021; Boom 2026), indicating potential applicability to other manufacturing organisations engaged in transforming raw ingredients to finished saleable products.

The UK's food manufacturing sector has a long history and is significantly embedded into British food culture and diets (Mallinson et al. 2016; Monteiro et al. 2018). At the same time, there is evidence for the growing adoption of complex and prepared foods globally as industrialisation of food supply chains continues to intensify (Monteiro et al. 2011; PAHO 2015). The UK's food manufacturing industry is considered highly developed (Cambridge Industrial Innovation Policy 2023; Kumar et al. 2017), with international collaboration and expansion increasingly becoming the norm (A. Bell 2026; Merson 2018). Given the ubiquity of factory scale produced sandwiches across Europe and the USA, the lessons learned from this study hold potential value for actors across these markets. As well as in retail operations, sandwiches are merchandised in transport hubs such as airports and railway stations, and show growth in new regions such as Asia and South America (Kelly 2026). While the scale and precise configurations may differ, general production and distribution processes are common across the industry. Thus, this provides an indication that the analysis of FLW dynamics and solutions may have transferability beyond the specific context of the UK food manufacturing sector.

In addition, results presented will be of interest to the growing tradition of researchers and practitioners examining the use of diagramming-based methods for knowledge and solution generation in complex social and technical contexts (Pope et al. 2021; Reed et al. 2017). The number of participants involved ($n = 35$) is limited, while it represented 5% of the company's work force and exceeds recommended minimum for this type of study

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(Braun and Clarke 2006; Bryman 2012). Difficulties in participant recruitment is reported in similar studies given the inaccessibility and time-poor nature of food manufacturing employees (Filimonau and Gherbin 2017). Due to such constraints, focus groups in this study took place on the manufacture's site rather than in external spaces, which could have had the possibility of restricting participant responses to conventional or accepted ideas. Yet, mitigation efforts were taken to address this through providing privacy in the location, anonymity in participant responses (Bryman 2012), and through the selection of the Rich Picture methodology, which is able elicit to tacit and taboo perspectives through the distance brought by the visual communication mode (Bell et al. 2016; Gisby et al. 2023; Kado et al. 2023).

Finally, while participants were selected from both operational and managerial levels across varying production processes, some areas of the business, such as product development or commercial relationships, were not included. Further work could explore the perspectives of individuals outside of the production process to FLW in the business and wider sector.

5 | Conclusions

Understanding the specific drivers and responses to FLW is paramount to identifying the opportunities for reduction and mitigation necessary to meeting global development goals (Buzby and Hyman 2012). Following a gap of in-depth knowledge of FLW creation outside the domestic sphere (Xue et al. 2017), this study provided an exploration of the FLW experienced in a UK food manufacturing company, adding to the small body of literature examining this context.

In the case study explored, FLW arises due to being unwanted or unsafe; the former being underpinned by high product visual standards and driven by processing inefficiencies, accidental damage and natural variation; the latter being caused primarily by stock management and co-ordination both within the operation and in the wider supply chain.

Demonstrating evidence for the adoption of Circular Economy principles, the analysis has provided a range of FLW prevention and utilisation opportunities of benefit to the sector, as well as discussing the organisational and legislative barriers the group under study have had to grapple with. By showing the interplay of internal and external factors, this study provides evidence for the necessity for collaboration between manufacturers and upstream and downstream actors, while the range of responses from internal stakeholders shows a necessity for cross-functional coordination and leadership for FLW mitigation within management structures.

Of particular relevance to policy makers is the finding that the typical approach of encouraging individual companies to monitor and reduce FLW within their operations may be inadequate; this study therefore calls for stronger governance and the use of systems perspectives across supply chains.

In addition, this study offers further evidence that targeting the consumer group for increased tolerance of visual variations may be fruitful for leading change along the supply chain. The limitations discussed in the previous section offer possible avenues for future research, in the extension of participant-led examinations of FLW dynamics to further food manufacturing companies, different product types, and other supply chain stages. Finally, further quantitative data on the comparative performance of different FLW prevention and management practices will help evidence the most impactful actions in the elimination of FLW in the food system.

Author Contributions

Alexander Moores: conceptualization, formal analysis, methodology, software, visualization, writing – original draft, writing – review and editing. **Dimitris Charalampopoulos:** funding acquisition, supervision, writing – review and editing. **Adrian Williams:** funding acquisition, supervision, writing – review and editing. **Ximena Schmidt Rivera:** conceptualization, funding acquisition, methodology, project administration, validation, supervision, writing – review and editing.

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Ethics Statement

Ethical approval was granted for the completion of this study from the Brunel University of London College of Engineering, Design and Physical Sciences Research Ethics Committee (reference 45264-LR-Oct/2023-47548-2) on 24th October 2023.

Conflicts of Interest

A.M. received funding from Samworth Brothers Ltd., industrial case study partner, during the research project. The academic integrity of the research was not impacted.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Analysis of Rich Pictures, Groups A–D, using Carney's (1994) critical framework. **Table S2:** Analysis of rich pictures, Groups E–G, using Carney's (1994) critical framework. **Table S3:** Sample of verbal data, associated codes and parent themes.

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