WP T3 - Deliverable 4.2

Business case for achieving 40000 tonnes of waste reduction

Improving Resources Efficiency of Agribusiness supply chains by Minimizing waste using Internet of Things sensors (REAMIT)

Executive summary

The REAMIT project is committed to addressing the pressing issue of food waste by embracing cutting-edge technologies and data-driven methodologies. Through the strategic deployment of Internet of Things (IoT) technologies and the Big Data analytics, the project aims to transform the agribusiness sector's approach to resource utilisation, supply chain efficiency, and waste reduction. At the core of this endeavor is a waste reduction framework seamlessly integrated with IoT sensors, facilitating real-time monitoring and comprehensive data collection on food quality. The integration of IoT technologies has empowered the project to gain unparalleled visibility into the various stages of the food supply chain. With real-time monitoring and data-driven analysis, REAMIT can detect anomalies and inefficiencies, thus enabling timely interventions to prevent unnecessary waste. By leveraging this data-driven approach, the project seeks to optimise production, transportation, and storage processes, ensuring that food reaches consumers with minimal waste.

In line with this vision, Deliverable 4.2 assumes a central role, leveraging the wealth of data generated by REAMIT's continual monitoring of sensor data. This deliverable will focus on identifying and saving potential food waste through advanced analytics, providing invaluable insights into the patterns of food waste in the North-West Europe (NWE) region. By using analytical tools, the project aims to offer a compelling justification for the potential avoidance of an astounding 40,000 tonnes of food waste.

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1. Introduction

Around 10% of food made available to EU consumers (at retail, food services and households) may be wasted [1]. These losses occurred at different stages of the food supply chain (FSC) i.e. in companies converting the raw agricultural materials into final products feasible for direct consumption [2]. Literature suggests that issues within FSC management leading to food waste are numerous, including inadequate processing and packaging, lack of transportation and distribution systems and inadequate storage facilities and techniques [3,4], and call for targeted action.

In particular, in the EU, nearly 57 million tonnes of food waste (127 kg/inhabitant) are generated annually, with an associated market value estimated at 130 billion euros [1]. By preventing food waste, companies can sell more food and create more revenue. However, the importance of reducing food waste has been recognised worldwide not only because food waste causes serious economic impacts but also due to environmental and social consequences [5]. Due to the amount of resources (water, nutrients, fertilisers, etc.) consumed during food production and distribution, food waste saved is much more than the face value of the waste itself for society [6]. Regarding environmental effects, the food sector accounts for over 30 % of global greenhouse gas (GHG) emissions [2]. Significant carbon emissions result from the production of food that is wasted, and the wasted food will emit more GHG in landfill, causing significant environmental impacts. To reduce carbon emissions, various companies have been seeking ways to reduce their own emissions [7].

Recent research supports the importance of using smart technology such as modern digital technologies (MDT), the Internet of Things (IoT), machine learning and blockchain to advance and improve FSC management [5,8–12] and thus help reduce food waste. The IoT is a growing network of objects that communicate between themselves and other internet-enabled devices over the Internet and allows users to monitor and control the physical world remotely [13]. In the supply chain context, Abdel-Basset et al. [14] defined IoT as a set of digitally connected physical objects for sensing and monitoring supply chain interaction, agility, visibility and information sharing to facilitate the plan, control, and coordination of supply chain processes within an organisation. In addition, adopting IoT is a potential opportunity to upgrade and reshape the FSC [12], and help data-driven decision-making in supply chain management [15].

This deliverable will provide a comprehensive overview of the REAMIT technologies and their implementation in pilot projects aimed at reducing food waste within the food supply chain. It encompasses an analysis of the cutting-edge digital solutions applied, the specific pilot companies that incorporated these technologies, the quantification of food waste avoided through their adoption, and the potential for scalability in other processes.

These pilots, conducted in partnership with companies, encompassed various stages of the food supply chain, including production, transportation, and storage. By implementing REAMIT technologies, these pilot companies effectively addressed food waste issues and showcased results in waste reduction. Within this deliverable, we will delve into the specific pilot projects that served as real-world testing grounds for REAMIT technologies.

2. REAMIT's Modern Digital Technologies Demonstrations

The project focuses on using innovative modern digital technologies to improve supply chain resource efficiency and reduce food waste in food supply chains. Researchers (academic experts) and practitioners (agribusiness organisations) have worked together to learn more about the issues related to the implementation of MDTs in agribusiness organisations. The action research of the project REAMIT involved the intervention and transformation in a dynamic process through the collaboration of researchers and practitioners in a business setting. The central part of the action research methodology is the demonstrations of the MDT in multiple agribusiness organisations (Figure 1). The REAMIT efforts in reaching out to agribusinesses resulted in technology demonstrations in multiple food businesses across Europe. The demonstrations primarily focused on food production and transport/storage stages of the food supply chains.

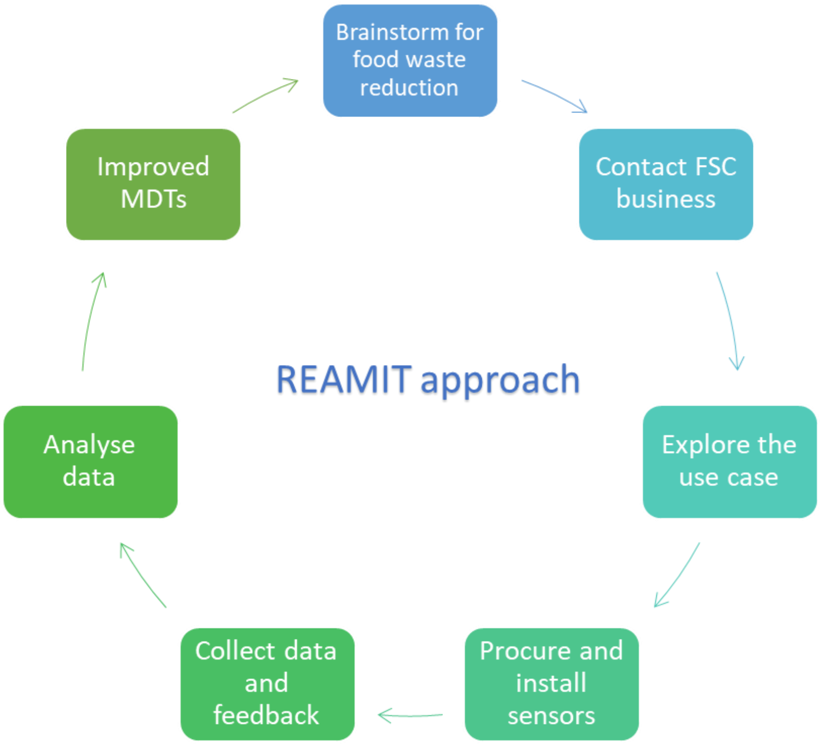

Figure 1. Approach adopted to collaborate with relevant agribusiness organisations.

The Table 1 lists all companies from agri-food supply chains in Northwest Europe, which engaged in REAMIT technology demonstrations (pilot tests). They were recruited for technology demonstrations in different stages of the REAMIT project implementation (in 2020, 2021 and 2022).

Table 1. Pilot companies recruited, location, stage of the supply chain where the MDT was implemented and the food products under analysis.

Pilot	Name of the company	Location	Stage of the Supply Chain	Food product
1	Burns Farm Meats	Ireland	Food processing in an abattoir	Meat
2	WD Meats	UK	Food processing in an abattoir	Meat, pork, lamb
3	Musgrave Group Ltd	UK	Transport	Groceries
4	YumChop	UK	Food storage in a frozen food company	Frozen, ready to eat meals
5	Human Milk Foundation	UK	Transport to human milk bank and hospitals	Human milk
6	Andy Keery Refrigeration	UK	Food storage in a refrigerated truck	Diverse products (food, flowers, etc)
7	BIOGROS	Luxembourg	Storage and transport in multiple stages of the supply chain	Groceries
8	Picnic	The Netherlands	Transport to customers' homes	Groceries
9	Glen Affric	UK	Processing	Wine
10	Weyers GmbH	Germany	Food production, storage and transport	Fresh vegetables, fruits, and herbs

Table 2 presents an overview of the pilot scenarios, the MDT deployed in each case, and the corresponding solutions or outcomes achieved during the demonstrations. By leveraging real-time monitoring and predictive models, these interventions aim to ensure the uniform distribution of temperature and other critical factors, mitigating food waste at various stages of the supply chain. Although some pilot initiatives were discontinued after implementation or discussion, it showcases the ongoing efforts to combat food waste and promote sustainability within the European food industry.

Table 2. Food waste issue and demonstrations of MDT for reducing food waste in European businesses.

Pilot	Food Waste Issue	MDT Deployed	Solution/REMARKS
1	Meat waste due to un-uniform temperature distribution in dry aging chambers (fridges)	IoT temperature, humidity, and pressure sensors located at multiple points to monitor uniform temperature distribution, and CCT and BDA-AI. Alerts via a smartphone and email	Ensure uniform distribution of air in the chamber. Send warning alerts if needed
2	Meat waste due to un-uniform temperature distribution in dry-aging chambers (fridges)	IoT temperature and humidity sensors located at multiple points to monitor uniform temperature distribution, and CCT and BDA-AI. Alerts via a smartphone and email	Ensure uniform distribution of air in the chamber. Send warning alerts if needed
3	Food waste due to temperature anomalies during transport	IoT temperature sensors located in fridge and freezer of the van to monitor temperature, and CCT and BDA-AI. Alerts via a smartphone and email.	Send alerts if temperature is not maintained within a pre-specified threshold.
4	Food waste due to inadequate temperature in fridges	IoT temperature sensors located in fridges to monitor temperature, and CCT and BDA-AI. Alerts via a smartphone and email.	Send alerts if temperature is not maintained within a pre-specified threshold
5	Food waste due to inadequate temperature during transport	IoT temperature sensors located in transport options to monitor the temperature, and CCT and BDA-AI. Alerts via a smartphone and email	Send alerts if temperature is not maintained within a pre-specified threshold.

6	Food waste due to inadequate temperature in fridges	IoT temperature sensors located in fridges to monitor temperature	Send alerts if temperature is not maintained within a pre-specified threshold.
7	Food waste is due to temperature abuse at the transport and storage stage of the supply chain	IoT temperature and humidity sensors located at each stage of the supply chain (farm, transport, storage), and CCT and BDA-AI.	ML model for early warning of product degradation given temperature.
8	Food waste due to the inadequate volume of icepacks used during transport	IoT temperature sensors located in the grocery transport crates to monitor the temperature, and CCT and BDA-AI.	ML model to predict quantity of ice required to maintain temperature given the weather and journey length.
9	Food waste of raw material when the right temperature and flow are not maintained in the production process	IoT temperature and flow sensors monitor temperature and other relevant parameters during production.	Discontinued after implementation.
10	Food waste due to temperature anomalies during transport	IoT temperature sensors located in transport options to monitor the temperature	Discontinued after initial discussion.

* Abbreviations: BDA-AI, Big data analytics and artificial intelligence; CCT, Cloud Computing Technology.

In the forthcoming subsections, it is present detailed insights into each assessed pilot, highlighting the specific food waste issues encountered, and the outcomes achieved. These assessments shed light on how the implementation of MDTs has significantly contributed to reducing food waste across different stages of the supply chain. The assessed pilots encompass a diverse range of businesses, including Burns Farm Meats, WD Meats, Musgrave, YumChop, Human Milk Foundation, and BIOGROS. Glen Affric and Weyers pilots were discontinued during their implementation. Additionally, due to insufficient data, the assessments for the Andy Keery and Picnic pilots could not be conducted at this time.

2.1 Burns Farm Meats

This pilot is a meat manufacturing company located in Ireland and produces meat from three different animals' livestock, cattle, sheep and swine. The pilot focuses on one facility where all processes take place. The processes involved in this pilot include livestock production, livestock reception, stunning and bleeding, removal of skin, head and hoof removal, splitting and evisceration, carcass chilling (dry ageing), and packaging. The annual production comprises, on average, 250 cows, 900 sheep and 480 swine per year.

The company uses local animal livestock located within a radius of 10-50 km. The livestock reception is the place where animals are kept when they are brought to the abattoir. Here, the selection of the animal to be moved to the slaughterhouse bay is made. From the temporary reception area, the animal is taken to the stunning point. The stunning of animals is used to render the animal unconscious before bleeding. In this abattoir, stunning is carried out using mechanical stunning. The bleeding process involves letting out of the blood when the blood vessel at the neck is severed. To avoid contamination, complete or almost complete bleeding is recommended, as bacteria can grow as a result of residual blood in the cattle arteries. Blood waste from the abattoir's bleeding area needs to be properly handled since it quickly starts microbiological development. Blood treatment was not considered in this study.

The removal of skin is carried out after bleeding. The process is done to prepare the muscle tissues beneath for consumption and the use/tanning of the skin. Manual skinning is used in this abattoir. After the skinning operation, the head and hoof are removed. After this process, the carcasses are washed and positioned for evisceration and splitting. The contents and bones are removed in this operation using a knife and saw. The carcasses are now transferred to chilling chambers for the dry ageing process. In this process, carcasses are put into a controlled open-air environment for 21 days (at controlled temperature, relative humidity, and airflow) to undergo a flavour transformation. By exposing the meat to air, moisture is pulled out, and the natural enzymes in the beef break the muscles down slowly over time, making it more tender. The company uses two chambers of different sizes (small and large) to store the meat. After chilling, the meat is transferred to tables for packaging and distribution to the market.

Some food loss can be observed during this process. For the purpose of modelling, inedible waste was defined as bones, blood, and skin, while edible waste included the trimmings generated after the 16-day dry-aging process. Table 3 presents the inventory of the company and the total meat production per year.

Table 3. BFM food production and waste generation inventory per year.

Unit Process		**Unit**	**Value**
Inputs			
	Cattle	kg	143750
Live animal	Sheep	kg	29250
	Pig	kg	63600
Outputs			
Products			
	Cattle	kg	74039
Meat	Sheep	kg	12494
	Pig	kg	39981
Wastes			
	Cattle	kg	63750
Inedible	Sheep	kg	15750
	Pig	kg	20400
	Cattle	kg	5961
Edible	Sheep	kg	1006
	Pig	kg	3219

Sensors were installed to monitor the temperature and humidity of the dry ageing chambers to ensure the meat was stored in the right conditions and to reduce the edible wastes. Four sensors were installed in the small chamber, and six were installed in the large chamber. The sensors transmit the temperature/humidity information to the Big Data Server via 4G network and alerts are sent when the temperature exceeds the acceptable limit (above 5 °C) via a specially designed interactive dashboard. This alert helps the company fix any malfunctioning of the chambers before the stored items go to waste due to temperature fluctuations. In this pilot, it is estimated that the implementation of IoT technologies prevented the trim losses during the dry-ageing process.

2.2 WD Meats

WD Meats is a meat manufacturing company that has been delivering meat products since its establishment in 1979. WD Meats expanded into beef manufacturing and set up its custom-built premises in Coleraine, on Ireland's North Coast. Over the years, WD Meats has experienced consistent growth, which can be attributed to its commitment to continuous development and improvement, both in infrastructure and professional skills. The company's modern facility spans 100,000 square feet and is located on a 35-acre site, providing an integrated processing operation.

It processes approximately 400 cows per day, and some carcasses are transferred to chilling chambers for the dry ageing process. In this process, carcasses are put into a controlled open-air environment for 21 days (at controlled temperature, relative humidity, and airflow) to undergo a flavour transformation, totalling 17 cycles. By exposing the meat to air, moisture is pulled out, and the natural enzymes in the beef break the muscles down slowly over time, making it more tender.

The company utilises a total of fourteen chambers for meat storage. After chilling, the meat is transferred to tables for packaging and distribution to the market. Approximately 4 % of edible waste is generated during the 16-day dry-aging and after the trimming process. The food production and waste generation are shown in Table 4 and represents the total meat processed in one dry ageing chambers per year.

Table 4. Meat produced and waste generated at WD Meats per ageing chamber.

Unit Process	Unit	Per cycle	Per year
Inputs			
Live animal	kg	7142.8	223468
Outputs			
Products			
Meat	kg	6859.5	119225
Wastes			
Inedible	kg	5714.2	99319
Edible	kg	283.3	4924

Sensors were installed to monitor the temperature and humidity of the dry ageing chambers to ensure the meat was stored in the right conditions. Four sensors were installed in the dry ageing chambers. The sensors transmit the temperature/humidity and alerts are sent when the temperature exceeds the acceptable limit (above 5 °C) via a specially designed interactive dashboard. This alert helps the company fix any malfunctioning of the fridge/freezer before the stored items go to waste due to temperature fluctuations. In this pilot, it is estimated that the implementation of IoT technologies prevented the trim losses during the dry-ageing process.

2.3 Musgrave Group Ltd

Musgrave Group Ltd. is an Irish food wholesaler, founded in Cork. It is currently Ireland's largest grocery distributor, with operations in Ireland and Spain. They operate from 10 warehouse locations in Ireland. Musgrave Northern Ireland, a subsidiary of Musgrave Group, has warehouses in Belfast, Lurgan, and Derry and is headquartered in Belfast, Northern Ireland.

On occasion, while performing deliveries to their business customers, the refrigeration units in the delivery vans operating in the greater Belfast area can break down, without any indication to either the driver or the logistics staff at the warehouse. The temperature in van carrying chill and frozen products would increase, surpassing the food storage temperature safety threshold, resulting in a van load of spoiled stock. It was estimated that out of their fleet of 5 delivery vans, at least one would suffer refrigeration problems over the course of a year. The vans have both a chill and a freeze zone, both of which should be monitored throughout a journey.

The average type and amount of products transported by markets like Musgrave per refrigerated van can vary widely depending on several factors, such as the specific market, location, season, and customer demand. Musgrave is a wholesale supplier and distributor, operating in the grocery and foodservice sectors in Ireland and the UK, so the types of products transported include fresh produce, dairy products, meat, seafood, frozen goods, and other perishable items. Based on general trends in food transportation and market size in Northern Ireland, it is reasonable to assume that a significant amount of food is transported by small, refrigerated vans to cater to various markets, including local markets, grocery stores, restaurants, and cafes.

The small refrigerated vans might serve both local markets and distribute food to more distant locations within Northern Ireland. Additionally, some vans may also cross the border to supply food to markets in the Republic of Ireland. The frequency of food transportation would depend on factors such as the van's capacity, the size of the markets, the type of food being transported, and the demand for perishable goods. Assuming the van operates daily, it could make around 3 to 4 trips per day. A total of 3 vans were analysed in this pilot.

The type of food transported include perishable items like fruits, vegetables, dairy products, meat, fish, and other temperature-sensitive goods. The amount of products transported in refrigerated vans will depend on the capacity of the vans used by the markets. The average capacity of refrigerated vans can vary but based on typical data for food distribution and transportation, the average capacity is 1 ton (or 1 pallet) of refrigerated cargo and 2 tons (pallets) of frozen food per trip. The estimated amount of refrigerated food transported can be found in Table 5. It has been determined that the quantity of frozen food is twice that of the refrigerated food.

Table 5. Estimated amount of refrigerated and frozen food transported per van per trip.

Mode of transport		Meat	Vegetables	Fruit	Dairy products	Seafood	Total
Refrigerated food transported per trip (kg)	Min	200	150	100	100	50	600
	Average	250	200	150	125	75	800
	Max	300	250	200	150	100	1000
Frozen food transported per trip (kg)	Min	400	300	200	200	100	1200
	Average	500	400	300	250	150	1600
	Max	600	500	400	300	200	2000
Total food transported per day per van (kg)	Min	1800	1350	900	900	450	5400
	Average	2625	2100	1575	1313	788	8400
	Max	3600	3000	2400	1800	1200	12000
Total food transported per month per van (kg)	Min	54000	40500	27000	27000	13500	162000
	Average	78750	63000	47250	39375	23625	252000
	Max	108000	90000	72000	54000	36000	360000
Total food transported per year per van (kg)	Min	648000	486000	324000	324000	162000	1944000
	Average	945000	756000	567000	472500	283500	3024000
	Max	1296000	1080000	864000	648000	432000	4320000
Total food transported per year per 3 vans (kg)	Min	1944000	1458000	972000	972000	486000	5832000
	Average	2835000	2268000	1701000	1417500	850500	9072000
	Max	3888000	3240000	2592000	1944000	1296000	12960000

Sensors were installed to monitor the temperature and humidity of the vans to ensure the food was transported in the right conditions. Sensors were installed in their fleet of 3 vans serving the Belfast area, allowing staff to monitor the temperature of the vans every 5 minutes. Automatic text alerts would be sent to the logistics warehouse staff when the temperature rose above a defined threshold limit during a delivery. It is believed that the REAMIT system's timely alerts were instrumental in saving the food from potential waste during at least one trip per month per van.

2.4 YumChop

Yumchop is a food manufacturing company located in the UK that prepares frozen food meals for customers via vending machines in which microwave ovens are integrated for heating the food. This innovative hot-cooked food business creates meals that combine multi-cultural traditions, responsibly sourced ingredients free from added preservatives, colouring or flavourings, and packaged in environmentally friendly recyclable and biodegradable packaging. The study focuses on one facility where the entire operations occur. The processes include raw materials acquisition from the supplier and transportation to the factory, manufacturing (vegetable, meat, poultry and dry ingredients preparation, cooking, finish goods and storage), distribution, retail and solid wastes treatment.

The food production and waste generation were collected through company interviews. The company uses locally sourced raw materials (vegetables and meat) to prepare their ready-meal products. Fresh vegetables (beans, pepper, etc.) are usually purchased from suppliers. The vegetables are manually washed, diced, and stored in a chest freezer. Meat (chicken and sheep) is stored in fridge storage as soon as it arrives at the production site. The meat is left marinating with oil and spices for two days in the fridge before cooking.

Once the food is cooked, it is transferred into a blast freezer to refrigerate the meals for approximately 3 hours. The food is weighed and manually packaged in paper boxes of 330g each. After this process, the boxes are transferred to long-term storage in a cold room with temperatures from -18 to -24 °C. Table 6 presents the total food storage in the company per week.

Table 6. Inventory of Yumchop food storage.

Fridge/Freezer location	Food type	Amount of food stored per week (kg)
Zone C Fridge	Raw materials (vegetables)	42
	Raw materials (meat)	117
Zone D Fridge	Raw materials (vegetables)	42
	Raw materials (meat)	117
Zone E Fridge	Raw materials (meat)	117
Cold Room	Product	52
Zone B Freezer 1	Product	52
Zone B Freezer 2	Product	52
Zone D Freezer	Product	52
Zone E Freezer	Raw materials (Vegetables)	42

REAMIT solution comprises digital sensors for measuring the specific parameters and the Big Data server. Eight sensors were installed to monitor the temperature and humidity to ensure that frozen food and raw materials for preparing the food are stored at the right temperature in the frozen food manufacturer's factory. Figure 2 presents the location of each sensor. The sensors transmit data via a GSM-based communication network every 20 minutes.

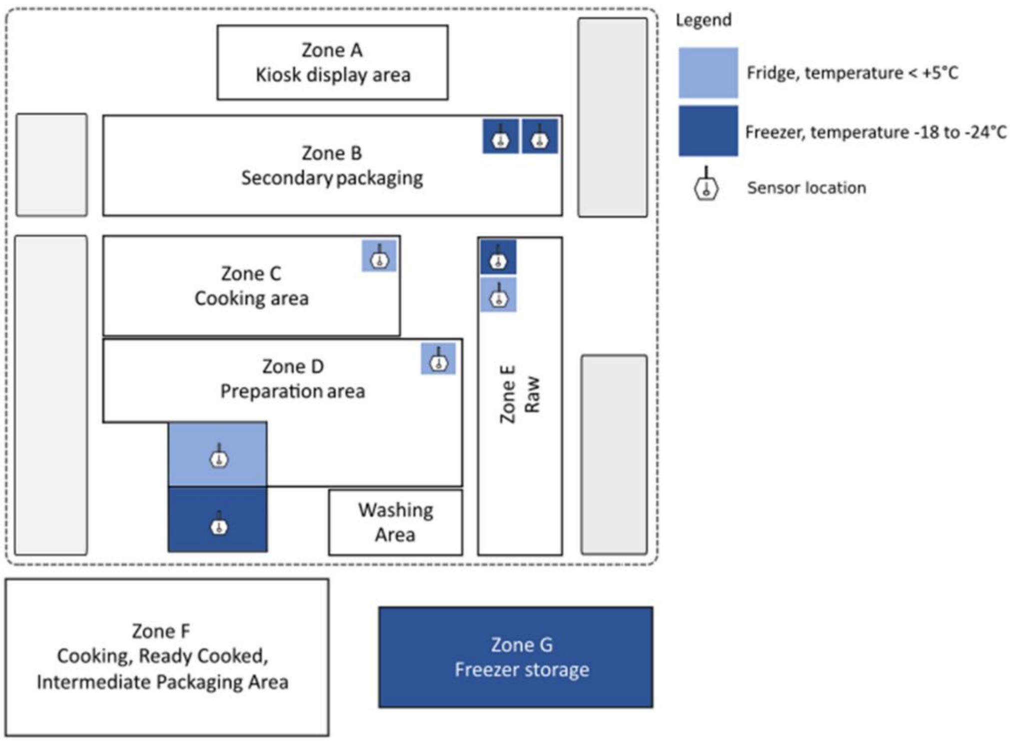

Figure 2. Layout showing the locations of REAMIT sensors in Yumchop's premises.

Although temperature monitoring and controlling are imperative measures of quality control, the fluctuations can be well within the acceptable range for ensuring the quality of food. Any measurement going beyond the suggested temperature range for a considerable time will result in food waste. Alerts are sent to Yumchop when two measurements in a row are over the temperature thresholds shown in Table 7.

Table 7. Temperature thresholds, food type and number of alerts for each equipment.

Equipment	Food type	Temperature thresholds	Number of alerts
Zone C – Fridge	Meat/Vegetables	+5 °C	50
Zone B – Freezer 1	Products	-18 °C	0
Zone B – Freezer 2	Products	-18 °C	0
Zone D – Cold room freezer	Products	-18 °C	10
Zone D – Cold room fridge	Products	- 18 °C	4
Zone D – Fridge	Meat/Vegetables	+5 °C	2
Zone E – Fridge	Meat	+5 °C	9
Zone E – Freezer	Vegetables	-18 °C	4

It was considered IoT technologies avoided wasting food products based on the alerts mentioned in Table 7. One year of data was analysed to determine the number of alerts, from 12th March 2022 to 12th March 2023. Temperature thresholds for food spoilage are those used for alerting at Yumchop defined on the Whysor platform.

The legal requirement in England, Wales and Northern Ireland, and recommended in Scotland for refrigerated foods state that it is recommended that fridges and chilled display equipment should be set at 5˚C or below. This is to make sure that chilled food is kept at 8˚C or below. If food has been kept at 8 ˚C or above for more than 4 hours, it should be thrown away [16]. Therefore, it was considered that threshold abuse for fridges needs recorded continuously for 4 hours before the load is considered waste. Once a load is considered waste, a 2-day period is applied to allow for stock to be replaced before checking for temperature abuse again (this is to avoid double counting food waste).

For frozen foods it is stated that a fully stocked freezer should stay at a safe temperature for roughly 48 hours if the door is kept closed. Without power, a half-full freezer should be safe for about 24 hours [17]. Therefore, it was considered that threshold abuse for freezers needs recorded continuously for 24 hours before the load is considered waste. Once a load is considered waste, a 2-day period is applied to allow for stock to be replaced before checking for temperature abuse again (this is to avoid double counting food waste).

2.5 Human Milk Foundation

This pilot focuses on one facility where the entire operations occur, the Hearts Milk Bank, located within the Rothamsted Institute in Hertfordshire. Hearts operates as part of the Human Milk Foundation (HMF), a charity dedicated to creating nationally equitable milk bank services. The mission of the charity is to support families facing feeding challenges in neonatal intensive care units through the provision of education and donor human milk (DHM), as well as where a bridge to a full milk supply is needed or lactation is not possible. Access to DHM is of particular importance for premature and very sick babies whose mothers temporarily or in the long term are not able to provide any or enough of their own milk. Hospital neonatal units are charged a fee to cover the milk bank's costs, but DHM and lactation support is provided free of charge to families who would not currently qualify on the National Health Service. The provision of the DHM is under the oversight of a healthcare professional.

HMF plays a crucial role in recruiting donors and ensuring the safe and controlled supply of donor milk to neonatal units and similar settings [18]. It oversees various processes, such as milk transportation from the donor's home/hospital to the HMB, processing (screening, pasteurisation, packaging and storage), transportation from the HMB to the hospital/recipient home and final treatment provided to all solid waste generated (landfill, and recycling). However, if the milk doesn't pass the rigorous microbiology tests both before and after pasteurisation, it is discarded [19]. The main factor involved in human milk wastage is microbiological contamination [20].

Donated milk is normally transported by blood bike motorcycle volunteers. Normally, between one and six volunteers make the transportations per day, totalling about 20 volunteers working at the HMB. The average amount of human milk transported per bag is 7 litres. The insulated bags can keep the milk frozen for up to 4 h. If the transport time is longer, it is necessary to use dry ice. The average transport distance during the first transportation (from donor/hospital to HMB) is around 50 miles, but it can achieve up to 100 miles per route.

The recently arrived frozen milk is unloaded, labelled for identification and transferred to freezers that maintain internal temperatures of at least -20°C. Four medical-grade freezers

(262 L capacity) and seven upright food-grade freezers (365 L capacity) are used to store the incoming milk, while three fridges (400 L capacity) are used for defrosting the milk at the HMB. The milk can be kept frozen for some weeks before the first screening. The milk is then defrosted, and samples from each batch are taken for microbiological analysis in accordance with the NICE Clinical Guideline [21]. After this process, the milk is pasteurised. The method involves heating the human milk at around 62.5°C for at least 30 min.

The processed milk is frozen and stored in freezers with a cooling capacity of -25°C. The milk can be stored for up to 6 months after the date of the first expression until expiration, but it is typically used in less than 3 months. Approximately 330 L of human milk were managed per month in the calendar year (Table 8), but output from Hearts is increasing by approximately 40% year on year. The percentage of milk discarded monthly (considered unsuitable for consumption) ranged from 11.3% to 17.9% over the last year (mean: 14.6%; Sept 2021 - August 2022), with the highest failure rates during the summer months (June - August).

Table 8. HMF production and waste generation inventory per year.

Unit Process	Value	Unit
Inputs		
Human milk pre-processing	3936	L
Products		
Human milk ready for donation	3361	L
Liquid wastes		
Human milk discarded	575	L

A strategy implemented in this particular HMB to ensure that the milk has remained in optimal conditions from the point of expression until fed to a vulnerable infant is to monitor the temperature and humidity during milk transportation using IoT technologies. A total of 12 sensors were installed to monitor the milk and ensure it remained in the right temperature and humidity condition. The Eagle datalogger (Digital Matter) was selected as the IoT platform, which formed the basis of the temperature and humidity monitoring system deployed in this human milk bank. The logger is an IP67-rated rugged cellular IoT device, supporting a range of inputs for various IoT applications. Each logger has four cell long-life power alkaline batteries, each with a capacity of 7800 mAh. Therefore, no other electricity or energy is required during the use phase.

Onboard, the logger contains a printed circuit board (PCB) with an array of sensor inputs, a GPS module and an accelerometer for geofencing and movement detection and is equipped with a cellular modem and sim card allowing the device to run on the IoT low-power LTE-M (CAT-M1) 4G network for data transmission. For sensing, the eagle was equipped with a T9602 temperature / relative humidity (T/RH; +- 2% RH, +-0.5°C, 0.01°C resolution) sensor probe (Amphenol, USA).

Currently, it is challenging to provide an exact estimation of the amount of human milk wasted during the transportation stage. However, on average, it is believed that the implementation of IoT technologies prevented the disposal of approximately 3% of the total 14% of discarded human milk.

2.6 BIOGROS

Biogros is a wholesaler for high quality organic and biodynamic foods (3.500 items in fruit, vegetables, dry goods and dairy produce). It has been supplying high quality organic food six days a week to their Luxembourg customers. Biogros stocks products from well-known organic brands like Naturata, Rapunzel and Lebensbaum, as well as organic products from lesser known or smaller producers. Thanks to their close collaboration with organic farmers from the cooperative Bio-Bauere-Genossenschaft Lëtzebuerg (BIOG), they also offer a whole range of regional organic products.

Biogros is a company with a complete supply chain. For example, fresh vegetables like celery, lettuce and mushrooms, produced by organic farmers from BIOG are transported from the farmer to the Biogros warehouse by Biogros trucks. In the warehouse the vegetables are packaged and then transported to the retail outlet, gastronomy business, large-scale kitchen or small village shop, that ordered the fresh vegetables.

The estimation of the food waste avoided was determined by considering only the food transported in each truck to avoid any duplication with the food stored in the warehouse. The average amount of products transported per refrigerated van can vary widely depending on several factors, such as the specific market, location, season, and customer demand. The types of products transported include fruit, vegetables, dry goods and dairy produce. The frequency of food transportation would depend on factors such as the truck's capacity, the size of the markets, the type of food being transported, and the demand for perishable goods. Assuming the truck operates six days per week, it could make around 3 trips per day. A total of 9 trucks were analysed in this pilot.

The amount of products transported in the trucks depend on the capacity of the vans used by the markets. The size class of the trucks vary but based it is in average 7.5-16t, while the average load factor is around 6 tonnes. The anticipated amount of food transported can be found in Table 9.

Table 9. Estimated amount of food transported per truck at Biogros.

Product	**Quantity per trip (1 truck)**			**Quantity per year (1 truck)**			**Quantity per year (9 trucks)**		
	Min	**Average**	**Max**	**Min**	**Average**	**Max**	**Min**	**Average**	**Max**
Vegetables	900	1200	1500	845100	1126800	1408500	7605900	10141200	12676500
Fruit	600	900	1200	563400	845100	1126800	5070600	7605900	10141200
Dairy products	600	750	900	563400	704250	845100	5070600	6338250	7605900
Dry good	1500	1950	2400	1408500	1831050	2253600	12676500	16479450	20282400
Total	**3600**	**4800**	**6000**	**3380400**	**4507200**	**5634000**	**30423600**	**40564800**	**50706000**

While receiving deliveries from BIOG organic growers in Luxembourg, Biogros noticed that the quality of fragile produce, such as mushrooms, unions, potatoes and celery roots, would occasionally not be up to standard. Biogros wants to gain insight in the climatic conditions (temperature and humidity) in the full supply chain, from grower to supermarket. For this, REAMIT selected the T9602 T/RH I2C probe by Amphenol (USA).

15 loggers “Eagle” and 15 RV/T sensors were purchased for the pilot test at Biogros and were installed in different departments inside the Biogros warehouse and inside 9 trucks. In 2022, 3 more sensor units were installed inside the warehouses of three BIOG farmers’ warehouses. For the trucks alerts are send when the temperature is above 10 degrees for half an hour and for the warehouse an email will be send, after one measurement, when the temperature is above 8, 10 or 12 degrees (depending on the sensor).

It is believed that the REAMIT system's timely alerts were instrumental in saving the food from potential waste during at least one trip per month per truck. Dry goods were excluded from the calculation of food waste avoided, as their non-perishable nature allows them to have an extended shelf life.

3. Optimising Food Supply Chains: REAMIT Waste Reduction

By leveraging MDTs and real-time monitoring technologies, food companies have successfully curbed food waste in different food categories. Table 10 presents the significant impact of implementing REAMIT technologies on reducing food waste across various pilot companies in the food industry.

Table 10. Estimated amount of food waste reduced due to REAMIT technologies implementation.

Pilot	Food type	Food waste avoided per year (kg)	Notes
Burns Farm Meats	Cattle	5961	Considering both chambers
	Sheep	1006	
	Pig	3219	
WD Meats	Meat	4924	Considering 1 chamber
Musgrave	Meat	27000	Considering 3 vans
	Vegetables	21600	
	Fruit	16200	
	Dairy products	13500	
	Seafood	8100	
Yumchop	Vegetables	2333	Considering 4 fridges and 4 freezers
	Meat	7117	
	Mixed products	722	
HMF	Human milk	118	
Biogros	Vegetables	129600	Considering 9 trucks
	Fruit	97200	
	Dairy products	81000	
Total		**419600**	

The results highlighted in Table 10 demonstrate the benefits of integrating REAMIT technologies into the operations of diverse pilot companies. At Burns Farm Meats, the implementation of REAMIT technologies led to significant waste reduction in cattle, sheep, and pig products, with avoidance amounts of 10.2 tonnes per year. WD Meats successfully minimised meat waste, avoiding approximately 4.9 tonnes per year, indicating the positive impact of REAMIT on meat preservation. Musgrave, with its wide-ranging distribution centers, achieved substantial food waste reduction across various food types. It is believed that the adoption of REAMIT technologies resulted in avoidance of 86.4 tonnes of waste per year. Yumchop managed to significantly reduce food waste in vegetables, meat, and mixed products, avoiding approximately 10.2 tonnes per year. Human Milk Foundation implemented REAMIT technologies to reduce waste in human milk, achieving a remarkable avoidance of 118 kg per year. At Biogros, substantial food waste reduction was observed in vegetables, fruit, and dairy products, with avoidance amounts of 307.8 tonnes.

In total, the combined efforts of these pilot companies using REAMIT technologies resulted in an estimated food waste avoidance of 419,600 kg annually, illustrating the remarkable potential of modern digital solutions in transforming food supply chain resource efficiency and waste reduction. The findings underscore the importance of technology-driven initiatives in fostering sustainability and combating food waste in the food industry. Figure 3 provides a visual representation of the distribution of food waste avoided as a direct result of implementing REAMIT technologies in all pilots on different food categories.

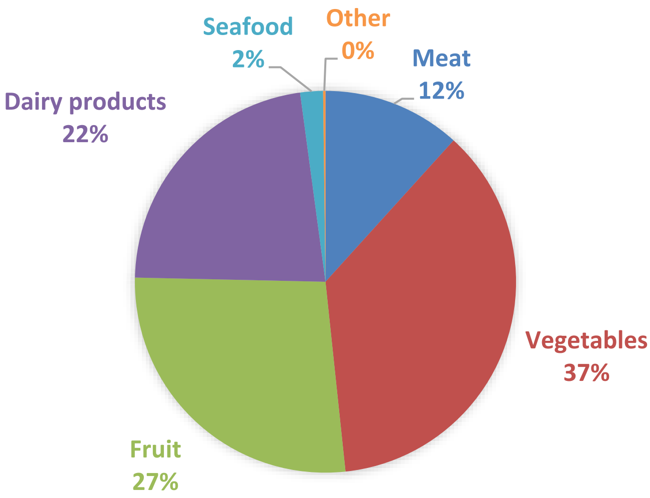

Figure 3. Distribution of the food waste avoided due to REAMIT technologies implementation.

Figure 3 illustrates the positive influence of REAMIT technologies in promoting sustainable practices within the food industry by significantly reducing food waste across various categories. Notably, in the case of vegetables, it has the most significant impact, contributing to approximately 37% of the total food waste avoided. It has also led to substantial reductions in fruit waste, representing about 27% of the total food waste avoided. Similarly, in the case of dairy products, it has effectively curbed food waste, accounting for approximately 22% of the total food waste avoided. Meat waste reduction accounts for approximately 12% of the total. While relatively lower, it has still contributed meaningfully to reducing seafood waste, making up about 2% of the total food waste avoided.

These results indicate that REAMIT technologies have successfully targeted a diverse range of food categories, encompassing both animal-based and plant-based products. The broad impact across different food types highlights the versatility and effectiveness of these technologies in optimising food supply chain resource efficiency and minimising waste.

4. Scaling up REAMIT's Modern Digital Technologies Demonstrations

The REAMIT project initially conducted pilot demonstrations to showcase the effectiveness of its IoT technologies. However, the potential for scalability to encompass the entire operations of the companies involved was recognised. Among the analysed companies, WD Meats, Musgrave, and BioGros stood out as promising candidates for the scaling-up of REAMIT technologies. This section analysis the potential additional food waste reduction due to the scalability of these 3 pilot companies.

In the case of WD Meats, the scaling-up scenario assumed the installation of REAMIT technologies in all 14 chambers instead of just one, maximising the impact of real-time monitoring and alerts to optimise temperature distribution.

Musgrave, with its extensive distribution network, presented significant scaling-up opportunities. They operate 3 main distribution centers (two in the south and one in Belfast) and 10 wholesale sites, supported by numerous delivery trucks serving over 1000 shops and restaurants. Additionally, there are approximately 5 vans deployed across each of their wholesale sites (totalling 50 vans), and around 200 trucks with a capacity of 7.5 tonnes of food. In the scaling-up scenario, the REAMIT technologies were assumed to be installed in all vans and trucks, enabling real-time monitoring and early warning alerts to prevent temperature anomalies during transportation.

For BioGros, which currently operates 9 trucks with REAMIT technologies, the scaling-up scenario encompassed the deployment of REAMIT technologies in 50 trucks, enabling precise monitoring and management of perishable goods during transportation.

The evaluation of scalability and the associated benefits for these three companies were presented in Table 11. By expanding the implementation to cover a broader scope of their operations, these companies could further optimise their supply chains, minimise food waste, and ultimately contribute to more sustainable practices in the food industry.

Table 11. Estimated of the potential food waste avoided through scaling-up REAMIT technologies in 3 pilot companies.

Pilot	**Food type**	**Potential additional food waste reduction per year due to scale-up (kg)**
WD Meats	Meat	68936
Musgrave	Meat	11250000
	Vegetables	9000000
	Fruit	6750000
	Dairy products	5625000
	Seafood	3375000
Biogros	Vegetables	720000
	Fruit	540000
	Dairy products	450000
Total (t)		**37779**

5. Global Conclusions

The implementation of MDTs has proven to be highly effective in reducing food waste across various food categories. The adoption of REAMIT technologies at Burns Farm Meats, WD Meats, Musgrave, Yumchop, Human Milk Foundation, and Biogros has collectively resulted in an estimated food waste avoidance of 419,600 kg annually. This exemplifies the immense potential of modern digital solutions in improving food supply chain efficiency and waste reduction while promoting sustainability in the food industry.

The distribution of food waste avoided across different food categories was also illustrated. Notably, REAMIT technologies made significant contributions to reducing waste in vegetables (37%), fruit (27%), dairy products (22%) and (12%) showcasing their versatility in targeting both plant-based and animal-based products.

Furthermore, the scalability potential demonstrated by the three pilot companies revealed the possibility of achieving additional food waste reduction by implementing REAMIT technologies across more operations. The combined impact of scaling up these operations amounts to an estimated reduction of 37,779 tonnes of food waste per year. This significant figure underscores the immense benefits that using REAMIT technologies can bring, as companies optimise their supply chains, enhance resource efficiency, and contribute to a more sustainable and responsible food industry.

We illustrated in this report that modern digital technologies could play a crucial role in food waste reduction in food supply chains. By continuously monitoring food environment conditions (temperature, humidity, etc.) along the supply chains, sensors can help ensure that food is stored and transported in optimal conditions during supply chain processes. Warning signals in the case of non-optimal conditions can be used to rapidly identify problems and retain optimal storage conditions. Significant food waste and equally significant carbon emissions can thus be avoided.

However, there are challenges to employing technologies for food waste reduction. As the business models have highlighted, companies specialising in technology must make efforts to publicise the value of these technologies for food waste reduction. We have so far approached a handful of food companies and demonstrated the benefits of using technology for food waste reduction. However, significant efforts are required to scale up these technologies. The following roadmap strategies are recommended to achieve a substantial target of reducing food waste.

1. Keep abreast of the latest developments in modern digital technologies and utilise the most cost-effective technologies.

2. Showcase a number of demonstrator applications of the use of modern digital technologies for food waste reduction in selected companies. Bring out all the elements of a sustainable business model (including the value proposition, creation and delivery dimensions).

3. Use the success of the demonstrators to reach out to more food companies. Explain the food waste saved, the carbon emissions avoided, and the social benefits derived from each demonstration case.

4. Reach out to more food companies. There is potential to reduce 107 tonnes of carbon emissions by working with meat companies each time a warning signal is sent. This can translate to significant tons of carbon emissions over a year. By reaching more meat companies, this saving can be much larger. For example, if 100 such companies are reached in one year, there is a potential saving of 10,700 tonnes of carbon emissions per year. Therefore, it is imperative to scale up the technology adoption by involving more companies in the next few years and save as much carbon emissions as possible.

5. Work with policymakers to incentivise food companies to use modern digital technologies to reduce food waste in their supply chains. This can be done, for example, by formulating guidelines, policy briefs, regulations, taxes and incentives and via appropriate labeling mechanisms confirming 'pro-active food waste reduction status'. This will encourage much wider deployment of modern digital technologies in food supply chains and will help avoid more food waste and reduce more carbon emissions in the future.

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