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Report on Domestic demonstrators

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OVERVIEW ON TASK 6.7

1 GENERAL SUMMARY

This report, D6.12: Report on Domestic Demonstrators, focuses on the development of two demonstrators for household applications (Demo 12, "Long term food storage," and Demo 13, "Next generation household refrigerator") and one demonstrator related to the reduction of Food Loss and Waste (FLW) (Demo 21). Both Demo 12 and Demo 13 aim to contribute to an energy-efficient food storage strategy for households and small businesses and can be effectively implemented in state-of-the-art cold-chain strategies.

The ”Long-term food storage demonstrator” focuses on implementing vacuum-freezing into small-scale freeze-dryers. That modification reduces both the freeze-drying time and the energy demand of the process. Hence, Demo 12 contributes to a more affordable (compared to standard market available freeze-dryers) approach for the long-term storage of highly nutritional foods (such as seasonal fruits or vegetables).

The “Next generation household refrigerator” demonstrator introduces innovative technologies and new components to household refrigerators. The refrigeration system developed for Demo 13 is based on blends of natural refrigerants (R290/R600a), including an Electronic Expansion Valve (EEV) and a new defrost cycle. In addition, the new thermal insulation materials were implemented in Demo 13 to minimise the head gains in refrigeration storage compartments. The coefficient of performance (COP) for the developed refrigerator was significantly improved. Consequently, Demo 13 achieves an A energy class, which contributes up to 12% of energy savings compared to the reference device.

The purpose of the Demo 21 on FLW is to design and test a conceptual digital tool for mapping food loss and waste, with the goal of collecting detailed data on waste categories, volumes, and the underlying causes or drivers. The tool prioritizes automation through digitalization, aiming to minimize additional working hours for data entry. This project has been carried out in collaboration with the Municipality of Trondheim in Norway, REEN Control, and led by SINTEF Ocean. It also identifies and facilitates the implementation of FLW reduction measures. Donation of surplus food is identified as a measure leading to reduced waste and emissions.

2 RECOMMENDATIONS

Using the results gathered during Task 6.7 execution, the following recommendations can be defined:

- Industry:
  - The advanced small-scale refrigeration cycles based on the natural refrigerants should be continuously improved by application of the refrigerant blends, new components or control strategies
  - Further possibilities of scale-down energy-efficient freeze-driers should be heavily studied
- Academia:
  - The robust mathematical models for the emerging cold-chain technologies should be developed by academia to support the industry’s effort in the implementation of the new technologies and control strategies

- Policy makers:
    - The possibilities of the food waste limitations via alternative methods, i.e. freeze-drying and digital tool for mapping food loss and waste should be emphasised by policymakers

3 DESCRIPTION OF THE SECTOR

The home refrigerator sector is a major segment of the global home appliance industry. It includes a range of refrigeration products used for everyday food storage and preservation in households. In Europe, annual energy use of refrigerators varies significantly based on size and efficiency label: small units consume around 70 kWh/year, while large American-style models can reach 390 kWh/year. Its market trends show a growing demand for energy-efficient and smart refrigerators with increased popularity of compact and modular models for small urban spaces.

According to the results from Demo21, the avoidable volume of waste is about 750 kg per month for a municipality as Trondheim (Norway). Long-term food storage sector focuses on preserving food for extended periods, often months or years. It involves the development and commercialization of compact, small-scale freeze-dryers (also known as lyophilizers) that integrate vacuum-freezing technology to preserve food, biological samples, or pharmaceutical products. Traditionally used in industrial or laboratory settings, these technologies are now being miniaturized and adapted for consumer, research, and specialty food markets.

4 DESCRIPTION OF THE TECHNICAL SOLUTIONS

The technical solutions implemented in Task 6.7 included: the vacuum freezing technology for the freeze-dryers (Demo 12), natural working fluids in refrigeration systems (Demo 12 and Demo 13), and the implementation of new system components and control strategies, e.g. new defrost cycle (Demo 13).

The employed vacuum freezing technology was implemented as the first stage of the freeze-drying process (instead of the atmospheric freezing). That freezing technique was enabled in the FrostX 10 freeze-dryer (https://frostx.com/en/product/freeze-dryer-frostx-10/). From a technical point of view, that modification was introduced mainly by modifying the control system of the freeze-dryer. The modification of the mentioned control strategy was based on the simulation (mathematical modelling) and experimental results.

The Demo 13 demonstrated the application of the most innovative technologies and control strategies for domestic refrigerator, such as new refrigerant blends, high performance insulated panels and defrost optimization. Various prototypes were created for testing these technologies.

A conceptual digital tool for mapping food loss and waste, by collecting detailed data on waste categories, volumes, and the underlying causes or drivers was demonstrated in Demo 21.

The main KPIs of each Demo are reported in the following table.

Table 1: Demo's KPIsDemo	KPI
Demo 12 Long term food storage	Mass reduction Energy consumption reduction Use of natural refrigerant
Demo 13 Next generation refrigerator	Energy consumption reduction Carbon emissions reduction Consumer electricity bills Use of natural refrigerants
Demo 21 Food loss and waste (FLW)	Avoidable volumes of FLW and costs for waste handling and treatment per month

PRESENTATION OF DEMONSTRATORS

5 DEMO 12 - LONG TERM FOOD STORAGE

5.1 Description

The “Long-term food storage” demonstrator is an alternative solution for a long-term food preservation that does not require energy input during the storage period. Namely, Demo 12 consists of a small-scale freeze-dryer enhanced by vacuum freezing. The concept of applying the vacuum freezing into the developed freeze-dryer is schematically presented in Figure *1*. As presented in the figure, the proposed technology results in the reduced process time and energy performance by integrating freezing and vacuuming processes and, in addition, partial drying of processed foods. Moreover, the developed device was equipped with a propane refrigeration unit integrated with the built-in crystalliser. As a result, the developed freeze-dryer is suitable for small businesses and household applications. The proposed technology was implemented into the commercially available freeze-dryer manufactured by the project partner FrostX.

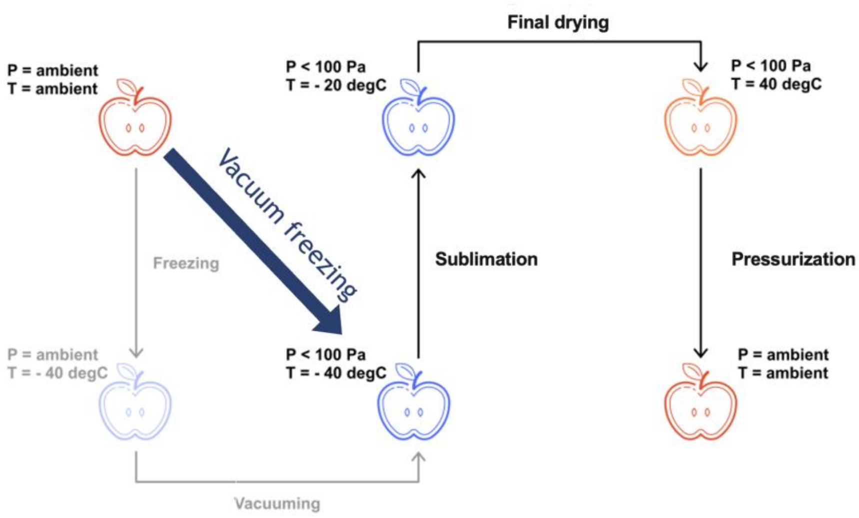


Figure 1: The scheme of the vacuum freezing implementation into the small-scale freeze-dryer

Consequently, the device with the vacuum freezing developed in Demo 12 was compared with a standard freeze-drying operation of the FrostX 10 device in terms of the overall performance and energy use for a drying cycle from a fresh to a completely dried product. The standard operation mentioned earlier device was assumed to be the reference technology used to calculate demo KPIs.

5.2 Application methodology and assessment

The development process of the vacuum freezing into the FrostX freeze-dryer included a multistep approach. First, the numerical model of the vacuum freezing was developed and validated for several food products. The numerical simulation results were used to define the initial control strategy for the vacuum freezing operation. Then the proposed control strategy was implemented in the FrostX freeze-dryer. Simultaneously, the hardware modifications, including the R290-based refrigeration system and vacuum control valve, were introduced into the prototype device.

The prototype was equipped with an additional set of instrumentation, such as T-type thermocouples for the product temperature analysis and power consumption meters for the energy performance evaluation. The initial tests were used to evaluate the cooling and freezing rate for the various goods, e.g. raspberries or banana slices. The cooling and freezing rates were assessed for the standard and vacuum freezing operations. Then, the extensive experimental campaign for the bulk load was conducted. These tests included the energy consumption analysis for the standard freeze-dryer and vacuum freezing-aided operation. To replicate end-user application and evaluate result under variable situations, the performed tests considered various fresh product loads, such as a mix of different fruits and vegetables, various masses of the load or multiple configurations of the vacuum freezing operation. Moreover, the influence of the sample shape was analysed.

5.3 Results

The initial results on various fruits (raspberries, banana slices...) showed that the cooling rate for vacuum freezing was approximately five times higher than that of the standard freezing mode. In addition, the processed products were partially dried during the vacuum freezing. The mass reduction of the analysed samples varied from 13% to 20% of the initial mass. As a result, the energy consumption of the whole process was reduced. In particular, the initial test showed an energy reduction (Demo 12 KPI) of up to 38% for a 3 kg load.

The next set of tests was conducted for mixed products (e.g. carrots and potatoes). These tests showed that the products shape is crucial in vacuum freezing efficiency. The best results were achieved for the thin slices of the processed foods. The temperature profile for 5 kg of sliced products during the vacuum freezing operation is presented in Figure 2. As seen in that figure, the temperature of the samples reached -30 °C in approximately 3.5 hours, while a similar temperature level was reached in approximately 5.5 hours for the standard operation of the device.

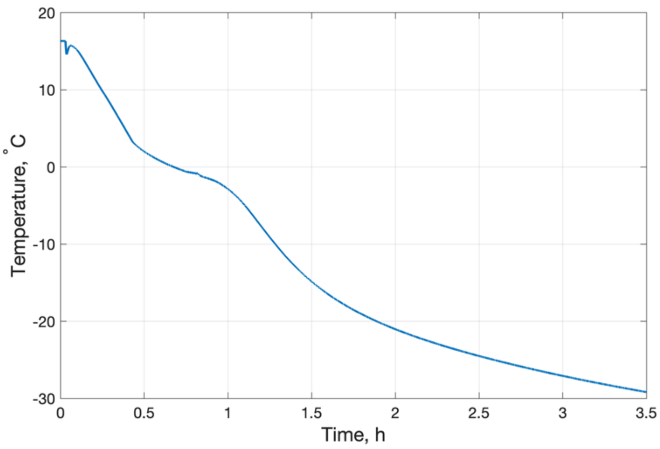


Figure 2: The temperature profile for the sliced potato sample during vacuum freezing.

Moreover, the temperature profile for the vacuum freezing operation was more uniform inside the device: the temperature decrease was similar for product located on the five shelves inside the prototype chamber.

The vacuum freezing process results in the evaporation of the processed product's moisture. Hence, during that process, simultaneous freezing and drying occur, which is considered beneficial from the freeze-dryer energy performance point of view. Figure 3 presents the mass reduction profile for the 5 kg of processed product. As can be seen, almost 20% of the water content was removed from the products during the vacuum freezing stage.

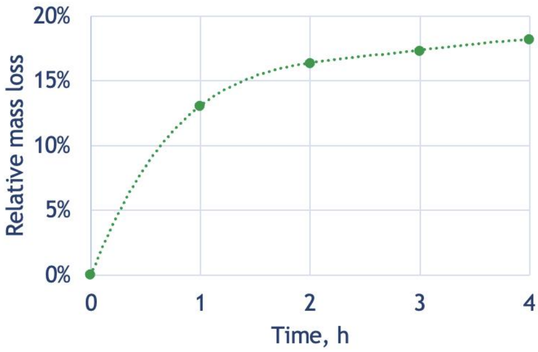


Figure 3: The mass reduction profile for vacuum freezing (left) and dried potato slices (right)

A detailed analysis of the energy demand of vacuum freezing was conducted. It requires the operation of the vacuum pump and refrigeration system. On average, the power demand of the vacuum freezing configuration was approximately 900 W, which is lower than that of the standard freeze-drying operation that requires heating system operation (six heating mats, 150 W/each).

The ongoing tests of the Demo 12 prototype include further process time reduction for various vacuum freezing times. These tests are conducted for bulk loads (5 kg or more) of mixed food products. The goal of these experiments is to tune the control system to maximise the mass reduction during the vacuum freezing process and reduce the process's standard freeze-drying and final drying stages.

5.4 Impacts

The biggest drawback of the currently available freeze-dryers is their relatively high energy demand and complexity. Consequently, small-scale freeze dryers could be considered unsuitable for domestic or small business applications. The technology developed in Demo 12 significantly reduces the process time and its energy demand. Moreover, the proposed freeze-dryer has an eco-friendly refrigeration system based on natural refrigerant (R290). The modifications introduced into the device controller enabled the vacuum freezing operation at the first stage of the process that reduced energy demand, especially for bigger loads of food products (> 3kg). The mentioned energy demand reduction was achieved for mixed products. Hence, the Demo 12 freeze-dryer is more suitable for household long-term storage applications and food waste limitations.

Due to the reduced energy demand, the developed freeze-drying technology is more affordable for non-industrial use. The employment of the Demo 12 freeze-dryer in households or small businesses (e.g., restaurants, farmers' markets) leads to notable reductions in food waste and the high nutritional value of stored goods. The proposed technology can be considered an interesting alternative for long-term storage of seasonal products such as fruits and vegetables. The freeze-dried products can be stored at ambient temperature for an extended time without any energy input. Consequently, Demo 12 can potentially change the cold chain regarding household food storage systems. Simultaneously, the energy demand reduction and R290 application result in a significant decrease in GHG emissions related to the long-term food storage.

5.5 Business potential

Demo 12 is a relatively novel approach for the freeze-drying. In particular, the developed device is compact, easy to use and energy efficient. Due to its small scale and intuitive control system, it is suitable for non-specialised/non-industrial small-scale users (including domestic application). Hence, the developed demo helps to create new markets for compact freeze-dryers in various small-scale applications.

5.6 Summary and further work

Demo 12 effectively demonstrates the feasibility of implementing advanced food preservation methods, previously exclusive to the industrial sector, in small-scale applications such as households. The primary goal of the developed Demo 12 was to reduce freeze-drying costs by improving the energy efficiency of the device. Simultaneously, the developed technology does not require significant modifications to the freeze-dryer components. On the other hand, the vacuum freezing implementation required the development of a new control strategy for the existing freeze-driers. To ensure the desired efficiency of the drying process, the control strategy was based on both experimental and computational results. The energy demand for the vacuum-freezing-aided freeze-drying process was compared to the reference freeze-dryer. The power consumption of the vacuum-freezing-aided process was reduced by up to approximately 30%.

The ongoing and further work on Demo 12 includes tuning the control system for various loads (e.g., mixed foods) and a further reduction in process time. A significant effort is invested in analysing drying curves for both the vacuum-freezing process and the standard freeze-drying process. These results will support the development of more advanced mathematical models to predict the process time for each stage of freeze-drying. Moreover, these models will take into consideration the amount and type of processed products.

6 DEMO 13 – NEXT GENERATION REFRIGERATOR

6.1 Description

As a consequence of the recent eco-design domestic energy labelling system update (labels A-G), it is projected that the average energy consumption in the domestic refrigerator market will be reduced up to 30% by 2025 (when compared to the current market). To achieve this goal, the project demonstrates the application of the most innovative technologies and control strategies, such as new refrigerant blends, high performance insulated panels and defrost optimization.

Figure 4: Technologies tested in new refrigerator

6.2 Application methodology and assessment

Various prototypes were created for the investigation of new technologies and the analysis of their effects. The literature review on the use of these technologies in other cooling products was also carried out and showed that they were at TRL 6-7 levels. After examining the effects of each new technology used on energy consumption, it was determined which ones should be used in 60 cm wide refrigerators.

Figure 5 **:** Refrigerator model for Demo 13

During the project, energy measurements were carried out in test rooms (heat chamber) at 16 and 32 °C ambient conditions. These studies aimed to attain 10% and above energy consumption improvement. In addition, refrigerators are being used in customers' homes in the field trial to learn the reactions of the customers. Thermocouples are used to measure the temperatures inside therefrigerators. Energy measurements are made under conditions where the fresh food compartment is 4 °C and the freezer compartment is -18 °C.

6

Figure 7**6:** Energy measuring station of the heat chamber

6.3 Results

Various innovative applications and technical improvements have been implemented in line with the goal of reducing refrigerator energy consumption by 10% compared to the refrigerator before being modified.

Improvement of Insulation Efficiency

More efficient insulation materials were used to reduce the heat gain of the refrigerator. As a result of the studies, better thermal performance was achieved using fewer vacuum insulation panels (VIPs). Consequently, the reduction in the number of VIPs contributed to a decrease in CO_2 emissions.

System-Level Optimization

By operating the system at a higher evaporation temperature within the full parallel cooling system, the system COP (Coefficient of Performance) was increased. New technologies such as electronic expansion valves (EEV) and optimized defrost functions were integrated into the system. These integrations enabled the achievement of the targeted 10% energy savings, and the refrigerator model has been made ready for mass production.

Component Analysis and Theoretical Evaluations

On the supplier side, a compressor with a 2% higher COP was identified and implemented. This improvement was confirmed through energy measurements, leading to the development of model "A," which consumes 12% less energy.

In the second phase, a new gasket design was developed to further reduce heat gain. Theoretical analyses indicated a potential improvement of 3.5% in energy efficiency. Measurements are currently ongoing, with results expected to be shared next month. Upon confirmation, total energy savings are projected to reach 15–16%.

6.4 Impacts

Since electricity production is usually done using fossil fuels (coal, natural gas, oil), reducing energy consumption results in less burning of fossil fuels. This reduces greenhouse gas emissions because burning fossil fuels releases carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. As a result, reducing the energy consumption of refrigerators is an effective way to reduce greenhouse gas emissions both individually and collectively. This is an important step in both protecting the environment and saving energy.

The demonstrator project aims to reduce energy consumption in domestic refrigeration through advanced technologies and system-level optimizations. The achieved and projected improvements are measurable through key performance indicators, while the broader environmental and societal benefits reflect the overall impact of the innovation.

Key Performance Indicators (KPIs):

Energy Consumption Reduction: Achieved up to 12% energy savings with current prototypes; projected to reach 15–16% with ongoing improvements.

Carbon Emissions Reduction: Lower energy usage directly reduces CO_2 emissions due to decreased fossil fuel-based electricity generation (depending on each Country emission factor).

Consumer Electricity Bills: The energy-efficient design leads to a notable reduction in household electricity bills, increasing long-term cost savings for end users.

Other Impacts

Food Waste Reduction: Improved insulation and stable temperature control extend food shelf life, particularly for sensitive items like dairy and produce, minimizing spoilage and waste.

System Performance: Integration of electronic expansion valves, high-COP compressors, and optimized defrosting improves system-level efficiency and reliability.

Environmental Impact: Reduced energy usage and minimized use of materials (e.g., fewer VIPs) lead to lower environmental footprint in both production and operation.

Technology Readiness: Technologies applied (e.g., variable-speed compressors, VIPs) are at TRL 6–7, showing readiness for broader market adoption.

Market Compatibility: Developed in line with EU energy labeling regulations (A-G), the refrigerator is ready for compliance and market launch.

6.5 Business potential

Developed following the regulations and standards valid in Europe, the refrigerator is expected to increase net profitability by increasing sales volumes.

7 DEMO 21 – FLW FOOD LOSS AND WASTE

7.1 Description

The aim of this demonstrator is to develop and test a conceptual digital tool to map the food loss and waste and to obtain detailed data on categories of waste, volumes and causes or drivers associated with it. The focus of the tool is on automatic registration using digitalization and avoiding increased labour hours for data registering. This activity has been carried out in collaboration with the Trondheim municipality in Norway, REEN control and SINTEF Ocean. The tool has been validated in real working environment at the production kitchen run by Trondheim municipality and data has been collected for a period of about 6 months during this project.

Case study: Trondheim municipality's Production kitchen

Background: Trondheim Municipality's production kitchen supplies 2,500 meals daily to households, nursing homes, schools, municipal and private institutions, and kindergartens. The distribution of chilled prepared and packaged food to consumers is done by trucks with a varying frequency for delivery. 35 employees who actively work with food and handle large quantities of food daily for e.g. 600-700 kg of salmon prepared in one day. The current biggest challenge is forecasting of production volume and uncertainty on the total sales. Due to cancellations of deliveries or less number of orders than expected, there can be an overproduction leading to food waste.

Figure 87: Portion packages produced at the production kitchen

7.2 Application methodology and assessment

The current practices of monitoring food loss and waste in the food chain, tools used for reporting and collection of data and the measures to reduce data have been mapped through several interviews. Semi-structured interviews were conducted with tailored questions for the different actors in the food value chain. The interview questions were designed based on the type of actor and included questions related to practices regarding monitoring and reporting FLW, tools used for reporting, main drivers and causes of FLW and potential measures for reduction. Table 1 includes a list of food chain actors and the focus on the interview questions.

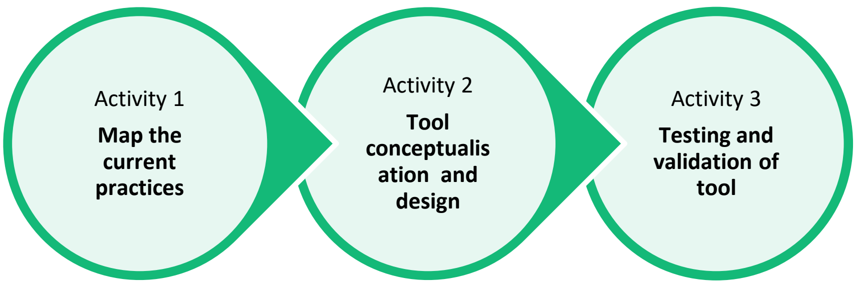


Figure 98: Workflow of this demo and the activities included

Table 22: List over the actors interviewed

Food value chain actors	Place/name	Focus of the interview
1 Dairy producer	Rørosmeieriet	Critical points where waste occurs and how it is monitored and reported.
2 Canteens	1 local Norwegian enterprise and 1 international chain	Main types of food waste (overproduction/plate waste), main drivers and identification of any trends
1 Restaurant	Local restaurant in Trondheim	Main types of food waste (overproduction/plate waste), main drivers and identification of any trends
1 Commercial Kitchen/Production kitchen	Owned by Trondheim Municipality in Norway	Main types of food waste (overproduction/plate waste), Composition of food waste, main drivers and causes, reduction measures
4 Supermarkets	4 different shops owned by different supermarket chains	Main food groups with largest volume of waste, how is it handled and treated, possible causes of waste
1 Food bank	In Trondheim region	Main sources where food is donated from, distribution network and logistics, data registering and need for insight on expected volumes of waste
1 nursing home	In Trondheim region	Main drivers of food waste, type of waste (leftovers, plate waste etc.), reduction measures and challenges
1 home care service	In Trondheim region	Frequency of plate waste and other food waste, possible reduction measures and
1 Digital monitoring tool provider	REEN Control	Features of the tool, its adaptability to the different food chain actors

The tool design, testing and validation included the following steps:

1. **Definition of the different categories of food loss and waste**
   During the first phase only 4 main categories were identified: Food loss (non-edible), Overproduction, Storage or supplier loss and Portion packages. After initial monitoring, the need for more insight in the Overproduction category was identified and hence 4 sub-categories are now added to the monitoring. These are vegetables, sauce, meat and fish.
   The destination of the waste for e.g. composting, municipal food waste treatment is also defined in order to calculate the exact emissions and costs associated with the collection and handling of treatment.
2. **Weighing and logging of FLW volumes and types**
   During the production the different categories of waste are weighed and logged into the tool with a varying frequency from several times a day to a few times a week.
3. **Testing of the monitoring tool 'REEN Control' and validation in real environment**
   The tool has been developed REEN AS mainly as a waste management tool for segregation and handling of different types of waste including paper, plastic, food etc.

The tool was customised for the production kitchen to specifically monitor food waste in the - pre-defined categories. The installation and start-up was carried out by REEN and Trondheim Municipality and the logging of data was carried out regularly from January 2025 onwards.

4. **Identification and implementation of reduction measures**
   Both implemented and potential FLW reduction measures have been identified and grouped into technical, organisational, regulatory measures.
5. **Long term improvement measures for the monitoring tool**
   Possibilities for additional functions like sending automatic notification on days with large variation in waste quantities, improving the background data on cost and emission for waste handling and treatment among others have been discussed with REEN AS.

7.3 Results

7.3.1 Interview

The main findings from the interviews are:

- There is no obligatory requirement on reporting food loss or waste separately for all the actors across the chain
- Energy use and solid waste from private actors (plastic, paper, EEA, mixed waste) is self-reported today to authorities
- Several different tools are used: Excel, NGflyt, Mathilda, REEN control for logging production, sales and waste data
- Inconsistencies observed in how emissions associated with FLW is calculated and reported
- There will always be unavoidable food waste, but end-of life treatment can be better in terms of waste hierarchy like processing to animal feed or insect feed vs. biogas or composting.
- At the nursing homes and home care services, there is some degree of food waste at the end consumer end mainly due to the factors like loss of appetite, loss of memory, personal food preferences among the elderly. The reduction of portion size is not possible due to mandatory dietary requirements that the production kitchen is required to follow.
- The drivers of FLW that are important for each actor are presented in the figure below

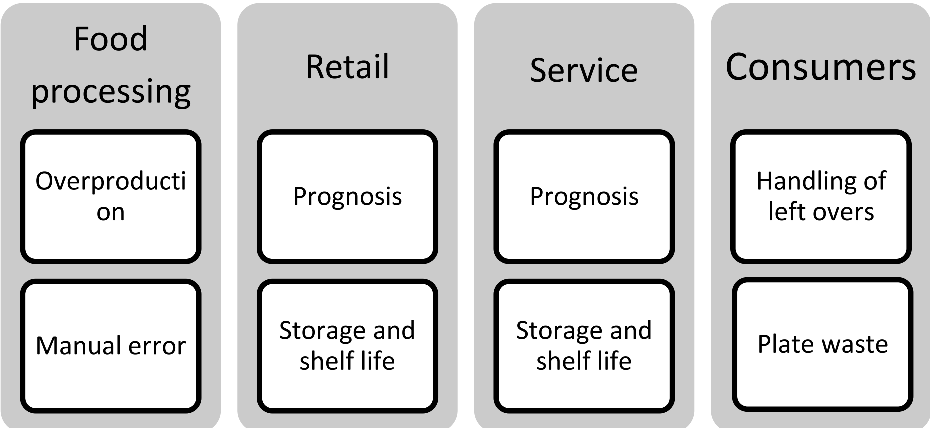
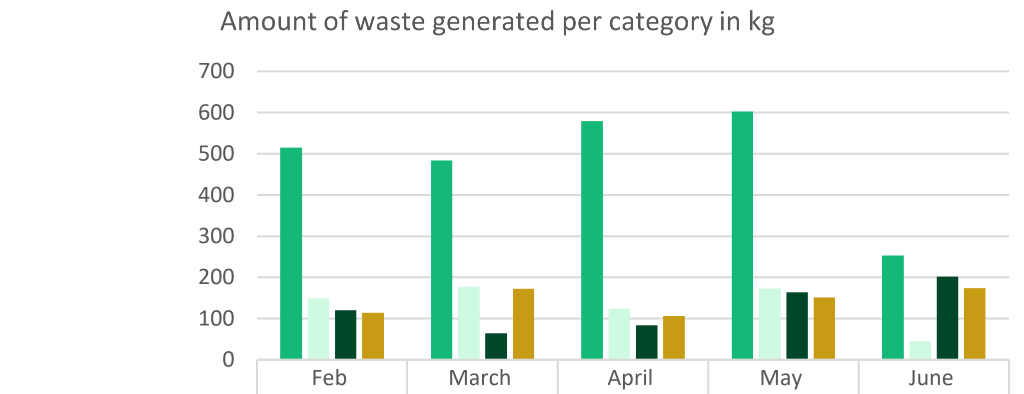


Figure 910: Drivers and causes of food waste at the different food chain actors interviewed

7.3.2 Findings from the Production kitchen

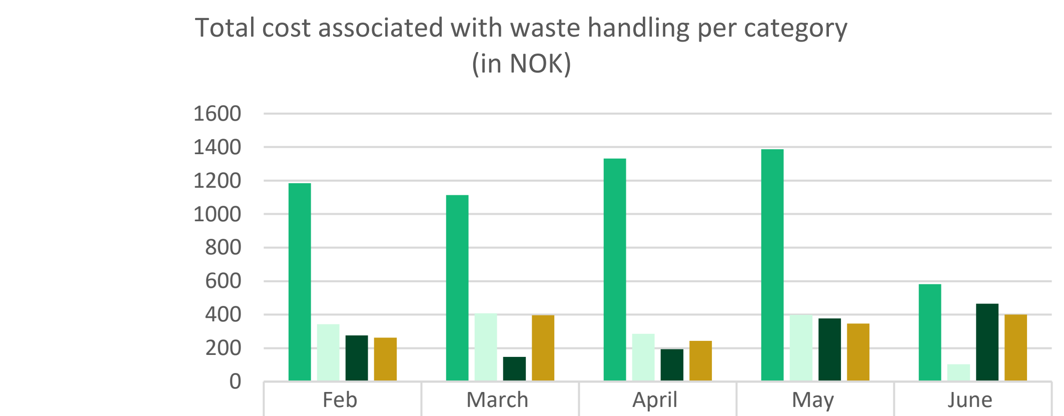
The waste quantities and costs associated have been monitored for the different categories of waste:



	Feb	March	April	May	June
Overproduction	515	484	579	603	253
Portion package	149	177	124	173	45
Storage	120	64	84	164	202
Food loss (non-edible)	114	172	106	151	174

Figure 1110: Data on FLW quantities from production kitchen

The category overproduction that also includes some amount of faulty manufacturing (e.g. manual error in weighing of ingredients, mechanical error due production etc.) is the highest volumes of waste followed by portion packages. The non-edible food loss including skins, peels, bones etc., is generated on a regular basis. The largest variation is in the storage losses which can be due to variation in how often the stock is checked and cleared of products that have passed the use before date.



	Feb	March	April	May	June
Overproduction	1184.5	1113.2	1331.7	1386.9	581.9
Portion package	342.7	407.1	285.2	397.9	103.5
Storage	276	147.2	193.2	377.2	464.6
Food loss (non-edible)	262.2	395.6	243.8	347.3	400.2

Figure 1112. Data on costs associated with the FLW generation and handling of waste from production kitchen

The cost for both packaged or unpackaged food waste is the same in Trondheim municipality and the food waste is handled by Ecopro[1]. A de-packaging machine removes all the plastic from the products and then it is turned into biogas and biofertilizer.

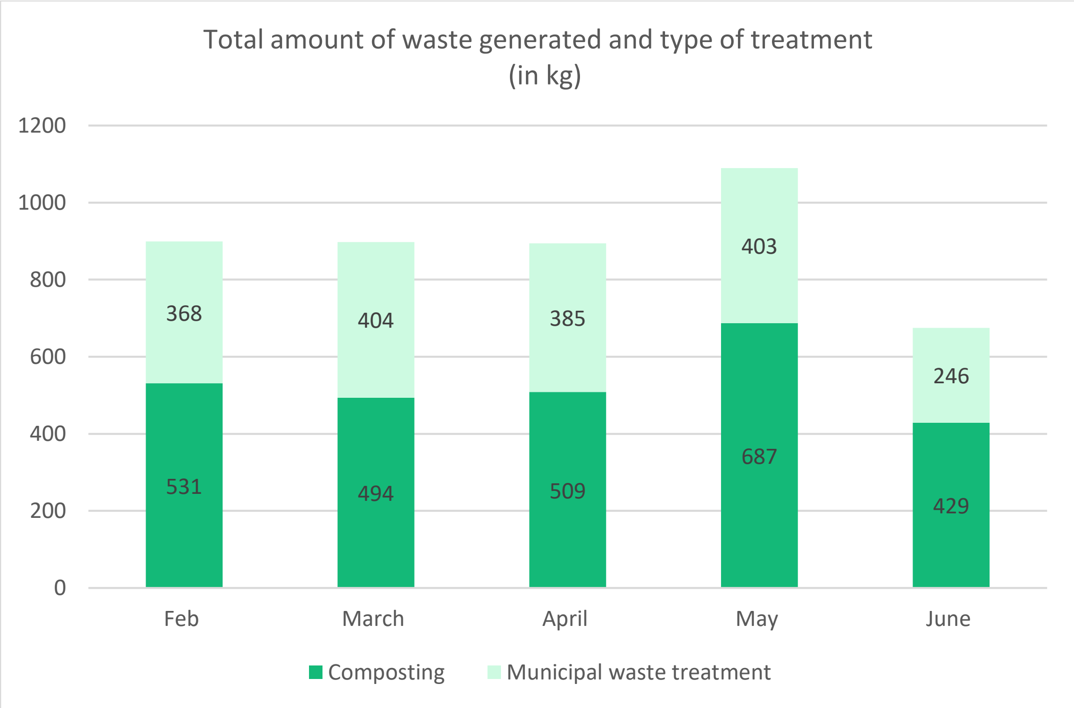
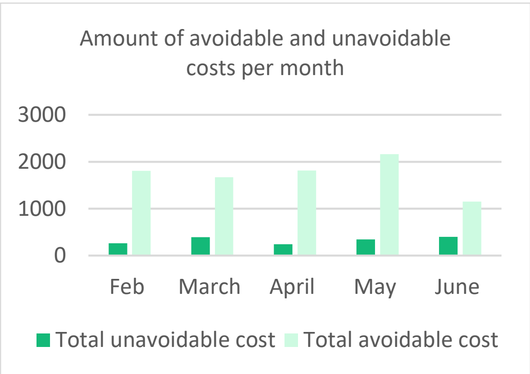


Figure 1312. FLW volumes and the end treatment of waste generated



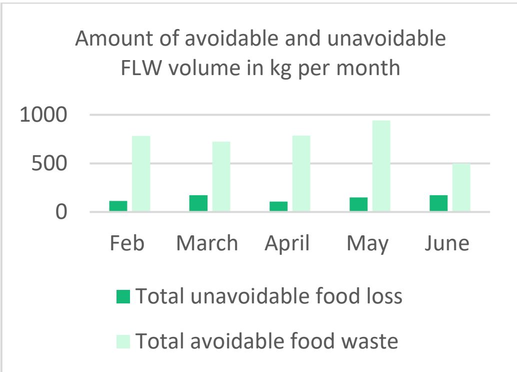


Figure 1413. Avoidable volumes of FLW and costs for waste handling and treatment per month

An average of 1700 NOK is the avoidable cost per month if the current volume of waste from excess production and storage is diverted to donation or any other purpose without any costs. The total amount of food that is wasted due to several causes is about 750 kg per month. The unavoidable food loss i.e. expected volume of loss that is associated with regular processing, is quite consistent while there are some variations in the amount of avoidable food waste.

[1] https://ecopro.no/

The production kitchen has implemented or is considering implementation of several measures during the project period that is summarized in the Table 2.

Table 33: Reduction measures for FLW identified and implemented

Type of measure	Reduction measure	Impact	Status
Organisational	Updating the cancellation policy and extension of the deadline from 3 to 5 days to allow enough time for re-distribution of cancelled orders.	Possibility for re-distribution → Less waste of 'ready to eat' portions	Implemented
Technical	Increasing the font size of best before date on packaging	Based on the feedback from interviews with nursing service, the font size was increased to ensure readability for the elderly and hence enabling them to be aware of the best before dates	Ongoing
Organisational	Donation of surplus food to the food bank	Reduced waste and emissions associated with waste collection and treatment and improved social impact	Ongoing
Organisational	Better communication with the end consumers with regards to packaging and handling of food	Maintaining the quality of leftover food, avoiding wrong practices of handling food that occasionally lead to waste.	Ongoing
Organisational	Preparation of a manual on ideas for using leftover food for nursing homes and some guidelines on handling, heating and storage of food	Avoiding food waste due to malpractice and maintaining quality of food	Ongoing
Technical	Large investment in new packaging machine that can fill and seal portions in separate compartment instead of one big one to allow to consume	Possibility for the end user to consume only half portion at once if preferred and better storage of left over food.	Discussed as a long-term measure

7.3.3 Conclusion

- The volumes of FLW, its composition and waste handling method have been identified.
- The relevant reduction measures both in a short- and long-term perspective have been identified, and a few steps towards implementation have been taken. Some of these measures include changes in the labelling to enable the elderly to read the best before date, exploring possibilities of donation of surplus food.
- The monitoring tool REEN control is validated in real environment and is well suited for monitoring of FLW both for large- and small-scale food production units.
- There is a significant emission saving from donation of excess food.

- The food waste at consumer end however is the most challenging to reduce due to human factors and nutritional requirements that the kitchen needs to adhere to.

Savings and KPIs:

1. **Cost saving:** The donation of FLW due to overproduction can results in a cost reduction of an average 1700 Norwegian Kroner per month.
2. **Food loss and waste saving:** The avoidable volume of waste is about 750 kg per month if the reduction measure such as donation is implemented.
3. **Emission savings:** The reduction of waste that is currently sent to biogas treatment plant can save emissions up to 30 CO2 equivalents per tonne of food waste.

7.4 Impacts

The impacts of the demo are as following:

- Improved data on volumes of FLW in the different categories
- Increased awareness among employees in the production kitchen as well as the nursing home and home care services
- Identification of additional FLW reduction measures both that are implemented and can be implemented in the future gives a good overview that is relevant to production kitchens in other municipalities all over Norway. The results from this study will be presented in Norwegian and dissemination will be directed towards the municipality.

7.5 Business potential

- Improving the functionalities of the tool with a possibility to send notifications in case of high amount of waste
- Better background data on the calculation of emissions and costs associated with waste handling and treatment

GENERAL CONCLUSIONS

8 GENERAL KPIS/IMPACT

The ENOUGH project, aiming to reduce GHG emissions in the European food chain supply by 2050, demonstrates several key impacts and contributes to overarching KPIs through its domestic demonstrators.

General Impacts:

The demonstrators collectively aim for new possibilities in energy-efficient food storage strategies for households and/or small businesses. Overall, a significant general impact is the reduction of Greenhouse Gas (GHG) emissions, primarily achieved through decreased energy consumption in refrigeration and food preservation processes.

Specific impacts from the demonstrators include:

- **Enhanced Food Preservation:** Demo 12, focusing on long-term food storage with vacuum-freezing, contributes to more affordable storage of highly nutritional foods and promotes long-term storage of seasonal products without energy input during the storage period. This leads to notable reductions in food waste.
- **Improved Energy Efficiency:** Demo 13, the next-generation refrigerator, achieved an A energy class, demonstrating up to 12% energy savings compared to reference devices. This reduction in energy consumption directly translates to less burning of fossil fuels and, consequently, lower CO2 emissions. Demo 12 also showed significant energy reduction, up to 38% for a 3 kg load, making freeze-drying more affordable for non-industrial use.
- **Food Loss and Waste (FLW) Reduction:** Demo 21's digital tool provides improved data on FLW volumes and categories, increasing awareness among employees in food production and care services. It also identifies and facilitates the implementation of FLW reduction measures. Donation of surplus food is identified as a measure leading to reduced waste and emissions.

General KPIs (Key Performance Indicators):

While some KPIs are specific to individual demonstrators, the overarching project goal implies general performance indicators related to sustainability and efficiency in the food chain.

Common and quantifiable KPIs highlighted across the demonstrators include:

- **Energy Savings:** A primary KPI, demonstrated by Demo 13 achieving 12% energy savings and Demo 12 showing up to 38% energy reduction in freeze-drying for specific loads. The goal for Demo 13 is to reach 15–16% total energy savings.
- **Greenhouse Gas (GHG) Emission Reduction:** A direct consequence of energy savings and food waste reduction. Demo 12 leads to a "significant decrease in GHG emissions" related to long-term food storage. Demo 21 indicates emission savings of up to 30 CO_2 equivalents per tonne of food waste if diverted from biogas treatment.
- **Food Loss and Waste (FLW) Reduction:** Quantified by Demo 21, with an avoidable volume of waste of about 750 kg per month if reduction measures like donation are implemented.
- **Cost Savings:** Associated with reduced energy consumption and food waste. Demo 21 estimates a cost reduction of an average of 1700 Norwegian Kroner per month if overproduction waste is donated.

9 DISSEMINATION AND COMMUNICATION

Publications:

“Performance evaluation of a domestic freezer with R600a and zeotropic mixtures of R600a/R290”, 15th IIR- Gustav Lorentzen Conference on Natural Refrigerants (GL2022). Proceedings. Trondheim, Norway, June 2022.

“Energy Consumption Performance Evaluation of a Household Refrigerator with Electronic Expansion Valve”, The 26th International Congress of Refrigeration (ICR2023). Proceedings. Paris, France, August 2023.

"The Effect of Capillary Tube Parameters and Use of Multi-Capillary on Energy Consumption in Vapor Compression Cycle", Cukurova 9th International Scientific Researches Conference. Adana, Turkey, October 2022

https://projects.research-and-innovation.ec.europa.eu/en/strategy/strategy-2020-2024/environment-and-climate/european-green-deal/green-deal-projects-support/green-deal-resources/food-waste-reducing-reusing-and-recycling-green-deal-call-funded-projects

What if your garbage had a nutrition facts label? – SINTEF Blog

10 GENERAL FUTURE OUTLOOK

These works have demonstrated many perspectives on potential future emission reductions across the domestic sector, in particular the use of natural working fluids, the implementation of new system components and control strategies and the application of different measures (donation, using monitoring tools) to reduce FLW.

The ongoing and further work on small-scale freeze-dryers involves fine-tuning the control system to accommodate varying loads (e.g., mixed food types) and to further reduce overall process time. Significant effort is dedicated to analyzing drying curves for both vacuum-freezing and conventional freeze-drying processes. The insights gained will contribute to the development of advanced mathematical models capable of predicting the duration of each freeze-drying stage. These models will also account for the quantity and type of products being processed.

The future outlook for next-generation refrigerators is highly promising, driven by regulatory alignment, technological innovation, and rising environmental consciousness. The project's outcomes not only meet current European energy labelling standards but also position these advanced appliances for broader market integration and systemic impact in both environmental and food security domains. This forward-looking vision is underpinned by several key factors:

- Compliance with the updated EU energy labelling regulations ensures strong market readiness and supports widespread adoption across Europe.
- The developed technologies—such as vacuum insulated panels (VIPs), variable speed compressors, and electronic control systems—can be applied to other cooling products, enabling expansion into new product lines.
- Reduced energy consumption contributes to global decarbonization efforts and fits within broader circular economy and climate action strategies.
- Enhanced temperature stability improves food preservation, helping reduce food waste and reinforcing resilience in global food systems.
- Project outcomes provide valuable insights for future regulatory development, particularly regarding eco-design and energy efficiency standards.

As part of the food loss and waste (FLW) demonstrator, efforts are underway to improve the functionalities of the monitoring tool. This includes developing features such as automatic notifications on days with significant fluctuations in waste volumes, and enhancing the background data used for calculating emissions and costs associated with waste handling and treatment. Addressing consumer-end food waste remains a major challenge, particularly due to behavioral factors and regulatory nutritional requirements in settings like nursing homes. Future strategies must explore innovative and systemic approaches to overcome these barriers. The implementation of targeted reduction measures is also ongoing. These include revising cancellation policies to allow more time for redistributing surplus food, enlarging "best before" date labels for better visibility—especially for elderly users—expanding food donations to food banks, and improving consumer communication on proper packaging and food handling. Additional measures involve developing user-friendly guidelines for managing leftovers and food storage in institutional kitchens, and exploring long-term technical investments, such as packaging machines with separate compartments to support partial consumption and improved storage. Finally, dissemination efforts focus on presenting the findings in Norwegian and targeting municipalities, with the aim of encouraging replication and scaling of best practices across production kitchens throughout Norway and Europe.