ENOUGH

EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

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Introduction to the ENOUGH project

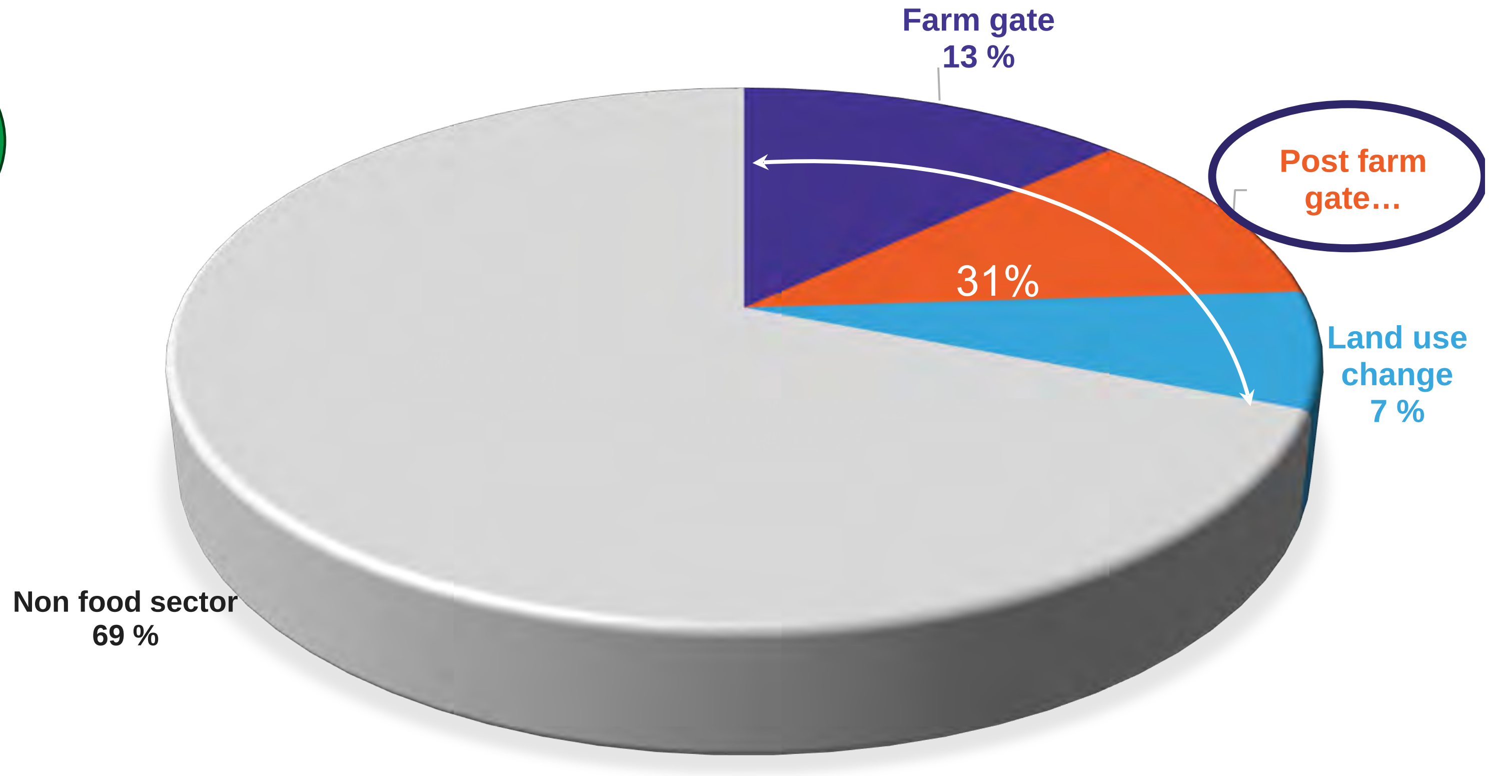
Hanne Dalsvåg

SINTEF Ocean

Demonstrator webinar
December 2023
Teams

ENOUGH: Decarbonising the food sector

1/3 of total GHG emissions related to food systems

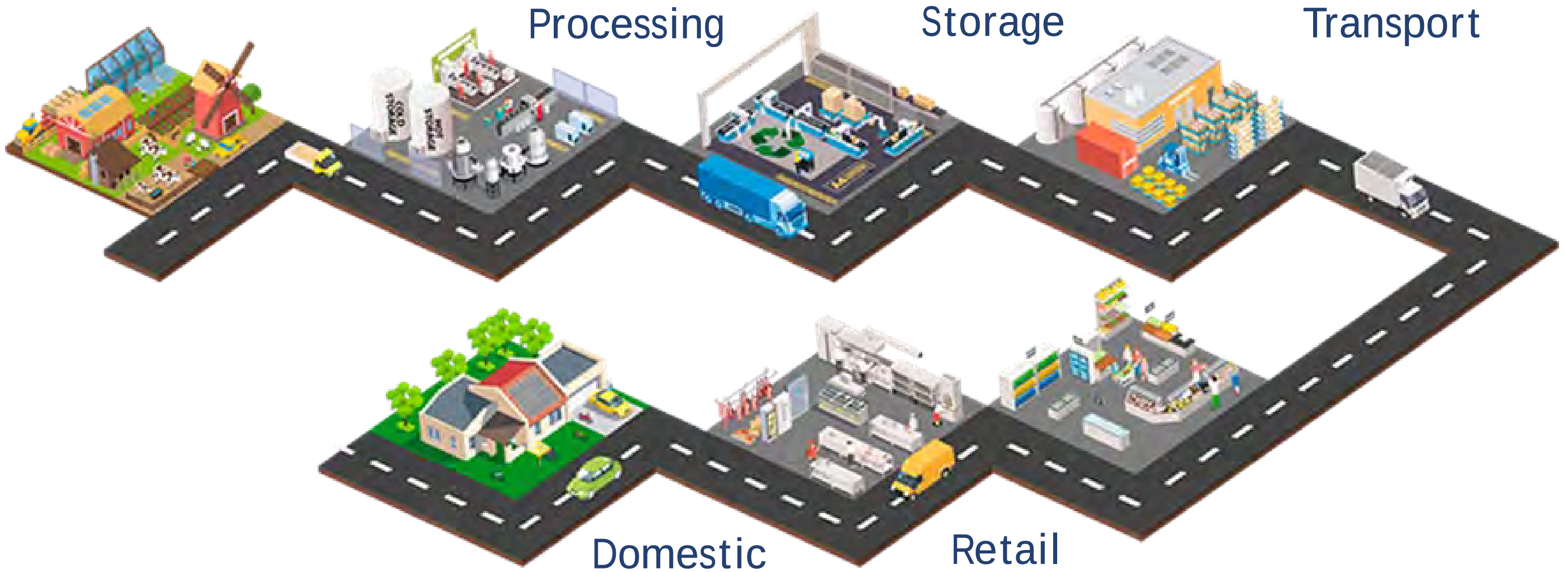


ENOUGH: Decarbonising the food sector

1/3 of total GHG emissions related to food systems

- Funded by the EU
- 4 year project within the EU Green Deal

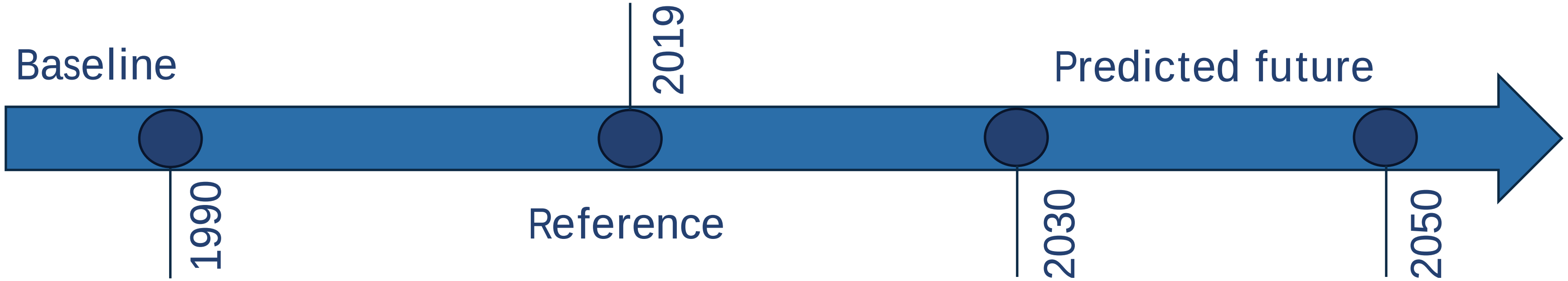
Goal: Reduce greenhouse gas emissions from the food supply chain
Aiming for a 55% reduction by 2030 and climate neutrality by 2050



Mapping and predicting GHG emissions

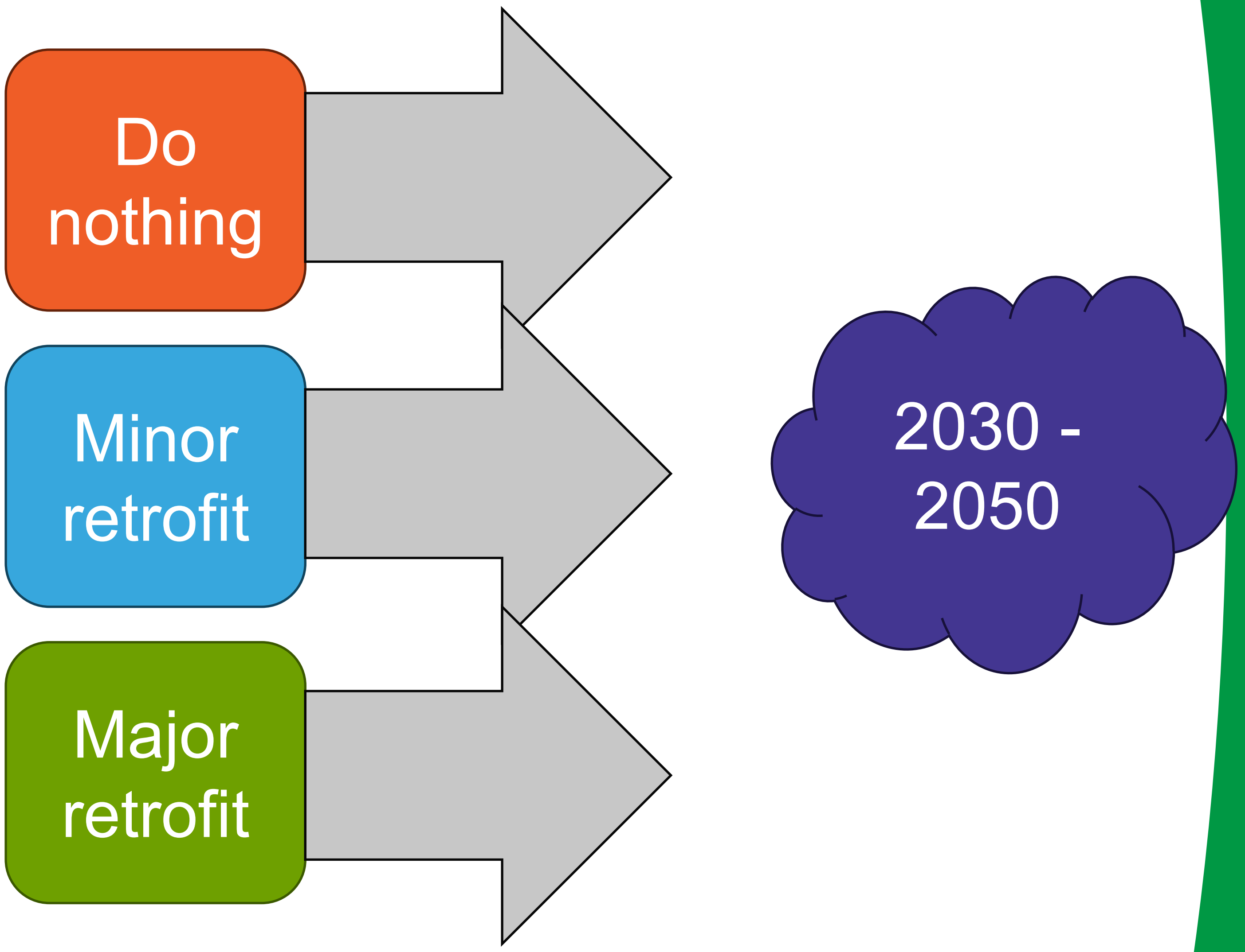
- Information available in data inventories – difficult to compare
- Models to quantify and calculate emissions in 1990, 2019, 2030, 2050
- Identify the sectors and technologies responsible for the majority of emissions
- Impact of future scenarios

We need to standardize data collection and availability



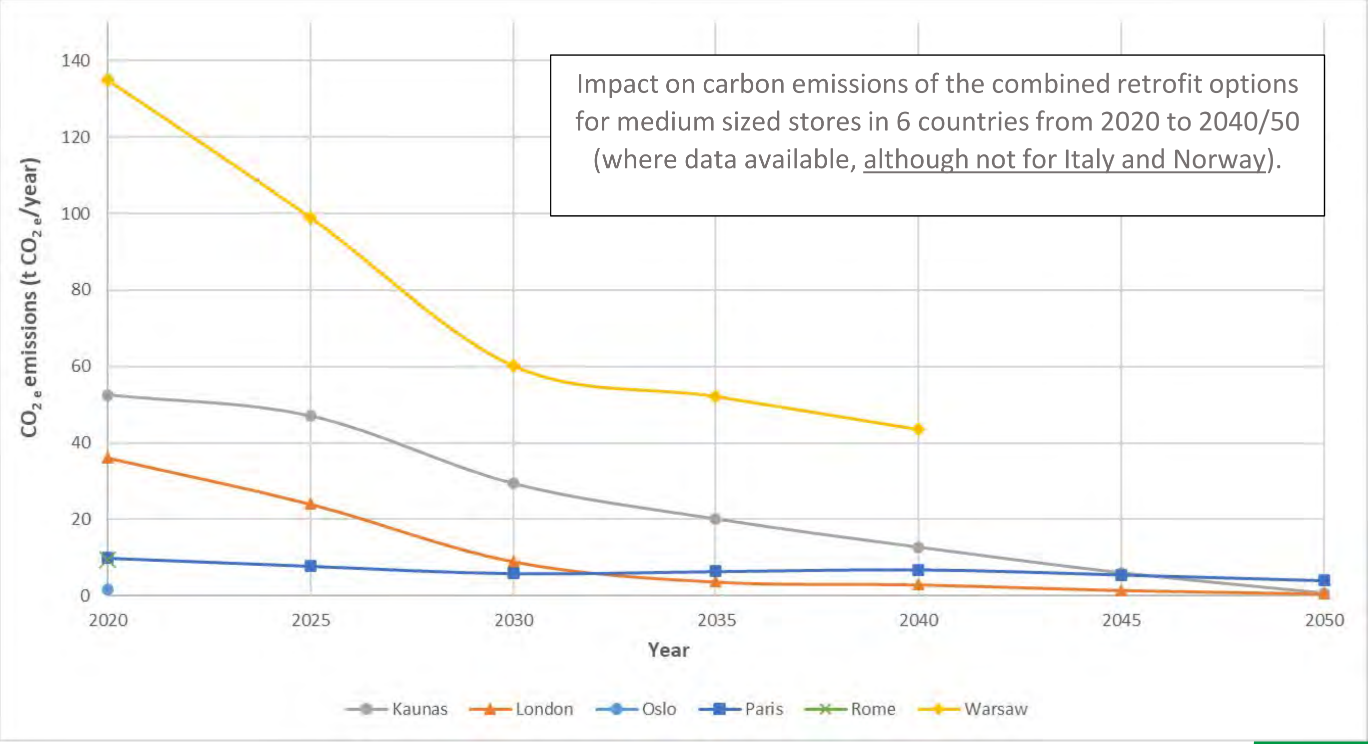
Technology roadmaps

- What is a roadmap?
- Technology reviews
- Modelling



Example: retail roadmap

- Review of 95 technologies
- 2 typical supermarket stores modelled
- 6 countries
  - Varied climatic conditions and grid carbon conversion factors
- Predicted energy savings from 55-94% and carbon emission reduction of 61-97%.



- Change to natural refrigerants
- Put doors on cabinets
- Energy efficient equipment

Calculation tools and smart data system

- Environmental impact of food chain is complex.
  - Calculation tools and smart data systems for decision making and evaluation
  - Should also be easily accessible for all
- ENOUGH tool evaluates emissions from food supply chain – identify the most critical point
- Combines quality and sustainability aspects at the same time

Only 3 steps

Select a product

Six main product categories have been considered: fruits, ready to eat meal, meat, fish, vegetable and milk products

Build the chain

Select every step, personalize them or just start with the reference chain for a first simulation

Simulate

Evaluate the evolution of quality, the energy consumption, compare your custom chain with the reference chain

Non-technological aspects

- Impact that non-technical issues have on energy consumption and emissions for food chain, including:
  - Financial requirements and business models
  - Public perception, social and behavioural barriers
  - Build upon the technological roadmaps
- Policy measures that concern the food value chain:
  - Food standards, industry and consumer initiatives
  - Policy measures and alternative road maps of policy actions
  - Policy recommendations and strategy advice for governments on how to reach zero emissions by 2050

At the core of the ENOUGH project is the demonstration of promising technologies to provide food companies tools, knowlede and evidence to reduce emission and improve energy efficiency

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101036588

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WP6 objectives

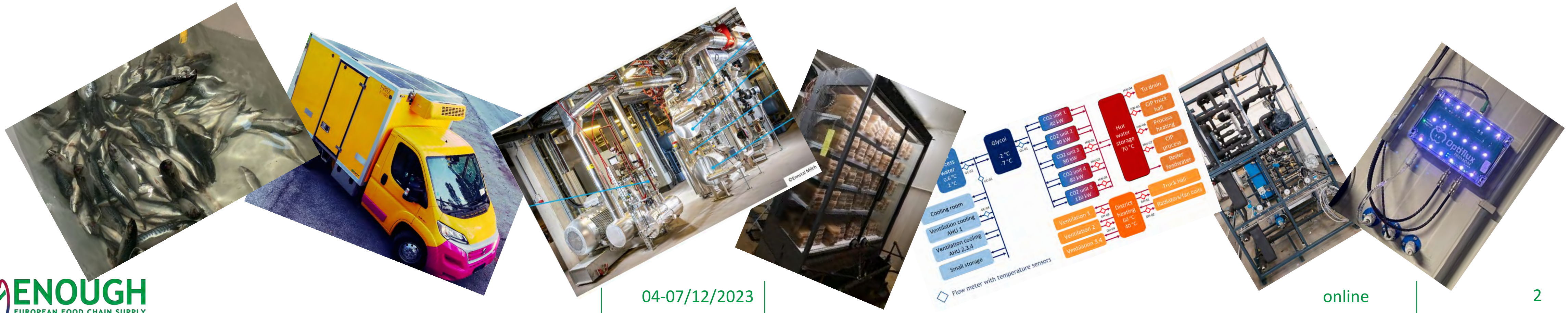
“Demonstrate **promising** **technologies** and **improve** their performance in **real-life situations”**

Relevant and viable TRL5-7 decarbonisation technologies

Real-life

Adapt, integrate, Improve

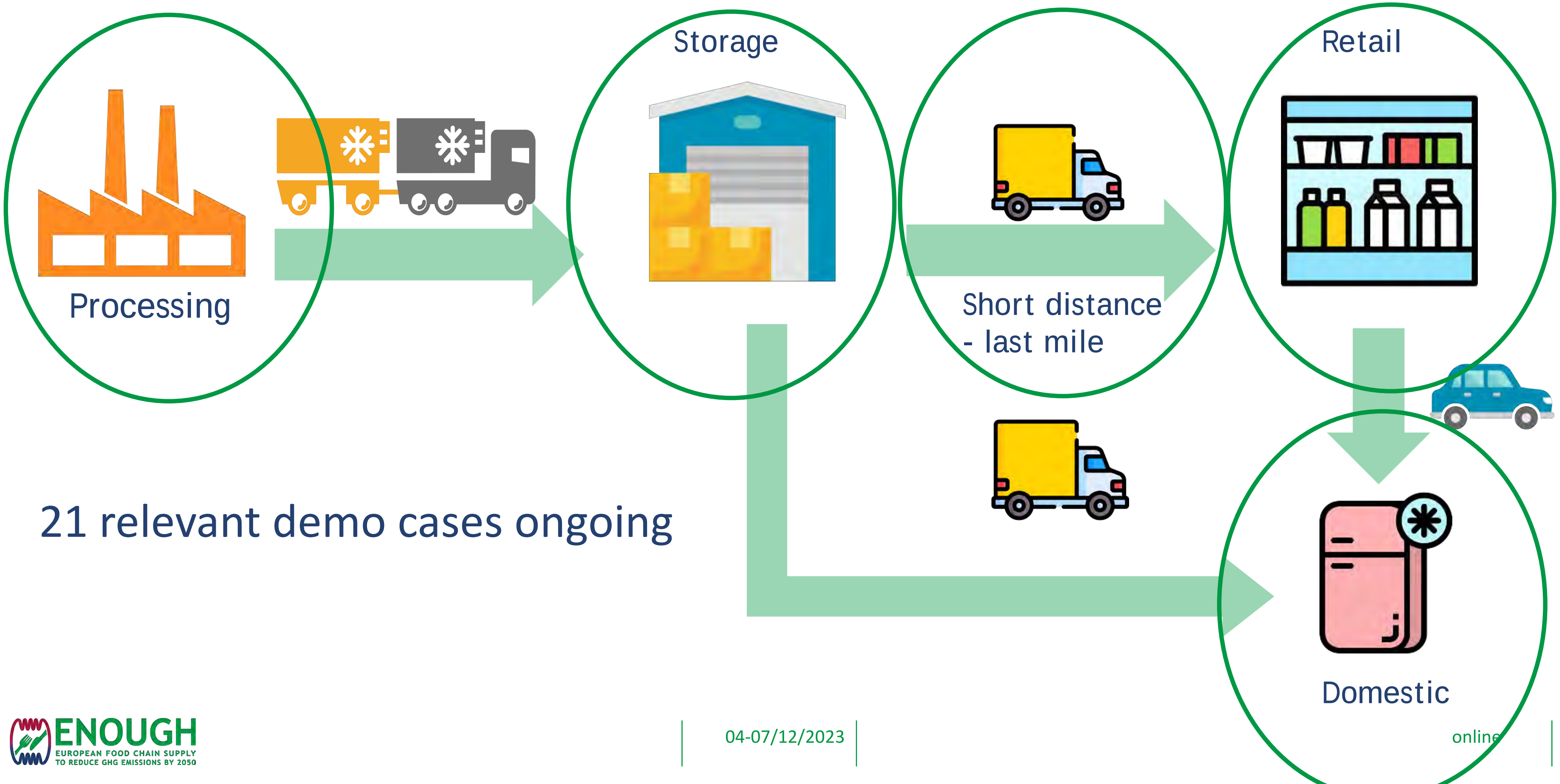
Measure



WP6 structure – product/process approach

	Meat	Fish	Dairy	Fruit&Veg	Other
Processing					
Transport					
Storage&Retail					
Domestic					
Other					

Food chain and demonstrators



21 relevant demo cases ongoing

WP6 Core strategies for GHG reduction

1. INTEGRATE AND OPTIMIZE ENERGY FLOWS
2. INCREASE ENERGY EFFICIENCY
3. REPLACE FOSSIL FUELS AND INCREASE RENEWABLES

HOW?

- **Heat Recovery** and **Thermal Energy Storage** (CTES and TES)
- Temperature level upgrade by **High Temperature Heat Pump** (HTHP)
- **Demand Side Response** (DSR)- integration with the grid, electrification
- **Efficient** components

WP6 Core strategies for GHG reduction

1. USE NATURAL WORKING FLUIDS and MATERIALS

HOW?

- Only **natural refrigerants** (carbon dioxide, ammonia and hydrocarbons) in all refrigeration and heat pump systems
- Sustainable packaging for sensitive products storage and transportation

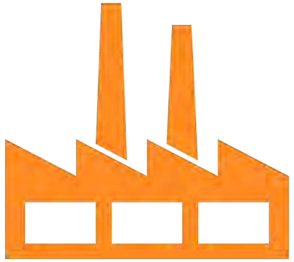
WP6 Core strategies for GHG reduction

1. IMPROVE PROCESSING AND PRESERVATION CONDITIONS
2. REDUCE FOOD WASTE

HOW?

- Adopt **improved** freezing techniques to maintain **quality** and prolong **shelf life**
- Promote innovative **preservation** techniques
- Utilize proper tools to **manage** and **monitor** the supply chain and **reduce food waste**

Demonstrators - Processing



3 Dairy

Heat Recovery, HTHP

TES and CTES

Natural Working Fluids (CO_2 and Ammonia)

3 Fish

Natural Working Fluids (CO_2)

Improved processing (Brine freezing, plate freezing and blast freezing)

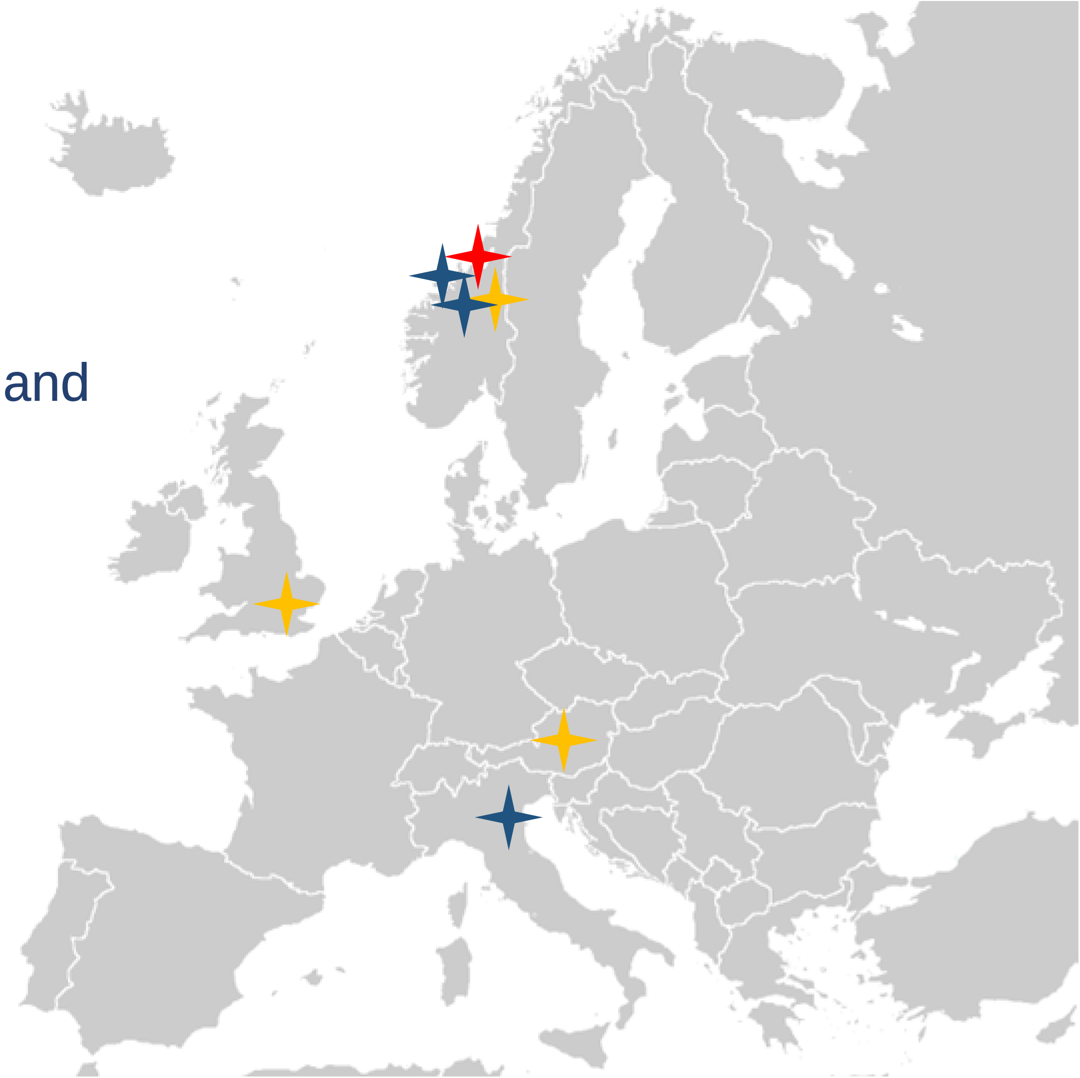
Improved efficiency

1 Meat

HTHP

Natural Working Fluids (NH_3-H_2O)

No fossil fuels - Improved efficiency



Demonstrators – Transport

2 Short distance, Last mile –
Mixed products
Electrification of refrigeration unit
Renewables (PV)
Use of NWF (CO_2 and HC)
TES

1 Transport – Fruit
Sustainable materials
(Carbon neutral packaging)
Improved preservation

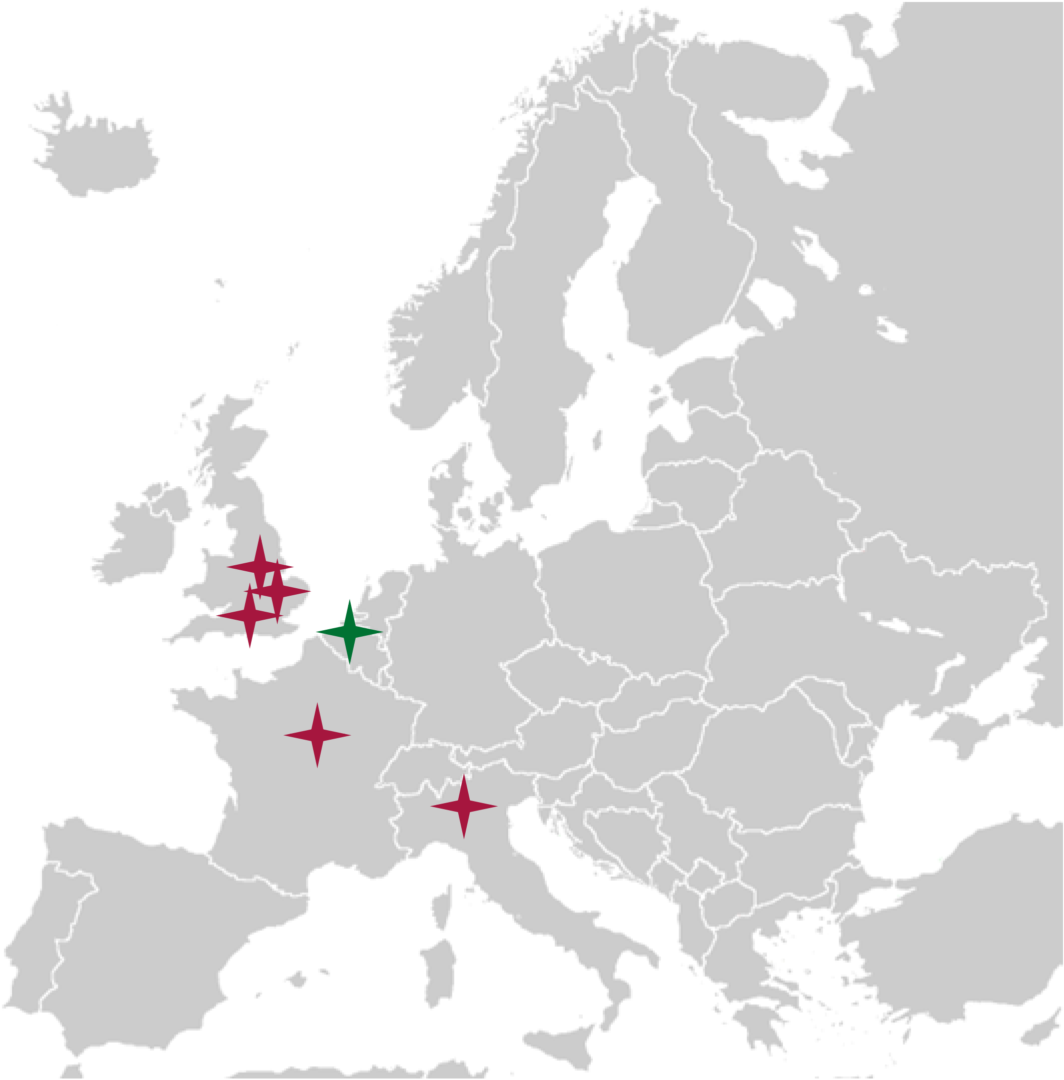
Demonstrators – Storage and retail

1 Storage – Mixed products
Heat Recovery

1 Storage – Fruit
Dynamically Controlled Atmosphere
Better efficiency
Natural Working Fluids

2 Retail – Mixed Product
DSR and TES (cabinet and system level)
Natural Working Fluids (CO_2)

2 Retail – Mixed Product
Energy Efficient Components (Cabinet and Refrigerating Unit level)
Natural Working Fluids (CO_2)



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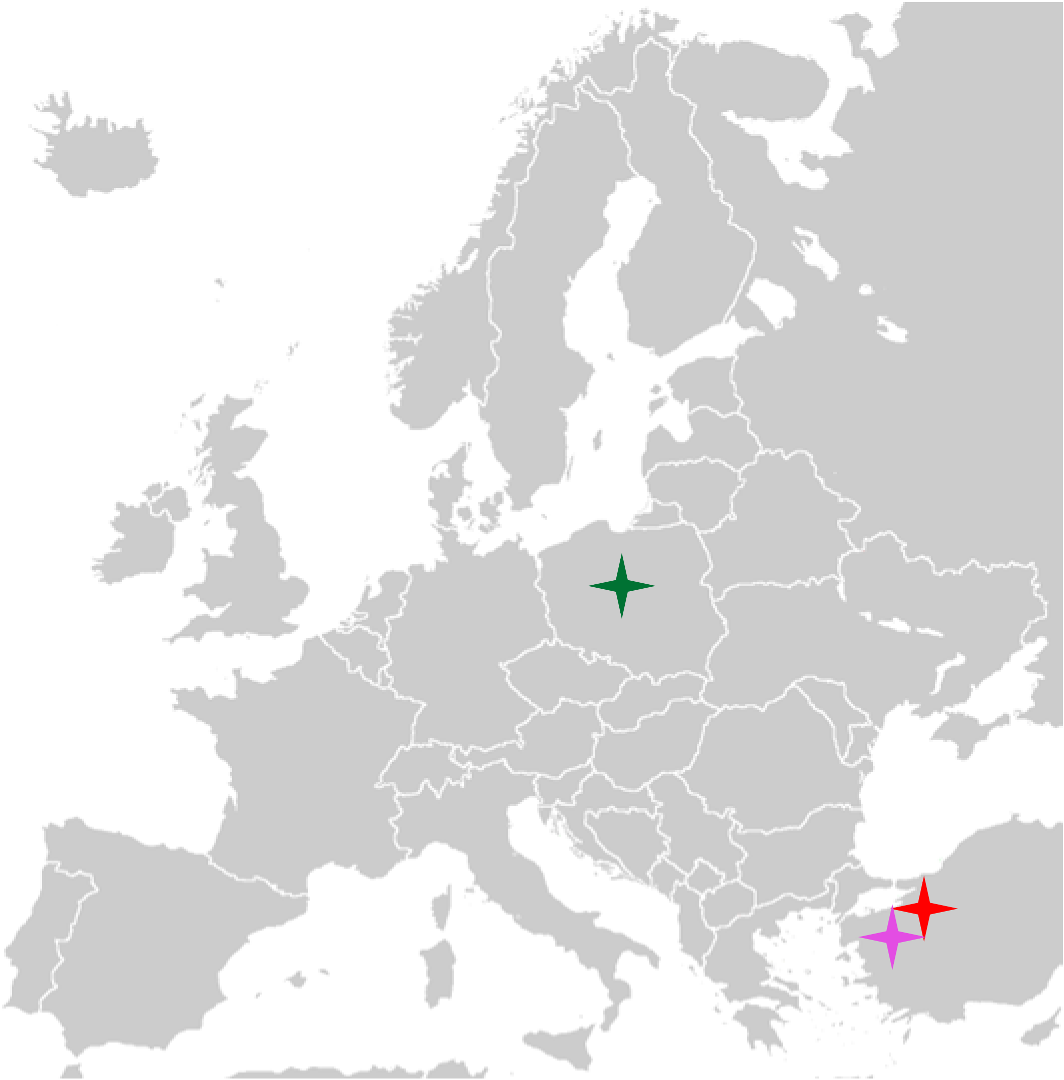
Demonstrators – Domestic

2 Domestic Preservation– Meat and Fruit&Veg
Improved preservation (superchilling and freeze drying)
Use of NWF (HC)
TES

1 Domestic refrigerator – mixed products
Energy efficiency
Natural Working Fluid (HC)

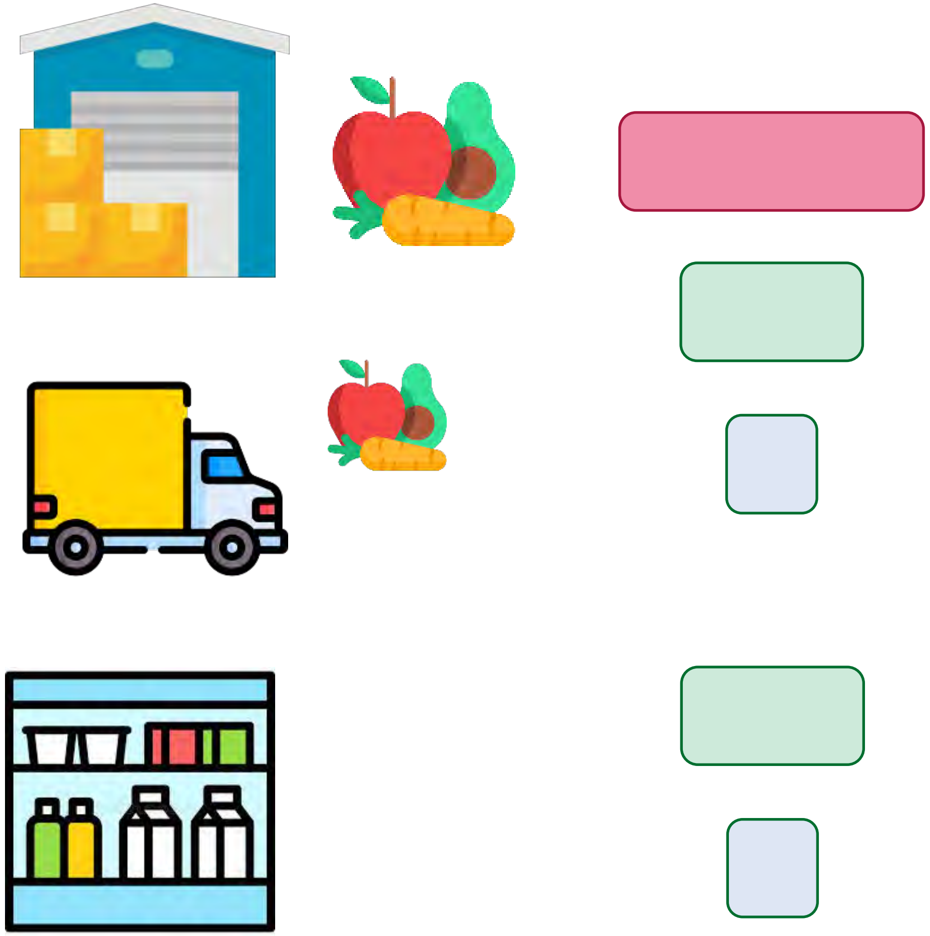


Demonstrators – Miscellaneous

1 Supply chain management and control – Mixed products

1 Food Waste Management – Mixed products

How to improve the sustainability of the food chain?– 7th December Webinar



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THANK YOU !

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Energy efficient dynamic controlled atmosphere storage

Pieter Verboven

MeBiOS Optiflux cbT

ENOUGH WEBINAR:

How to improve the sustainability of the food chain?
7/12/2023

Controlled atmosphere (CA) storage

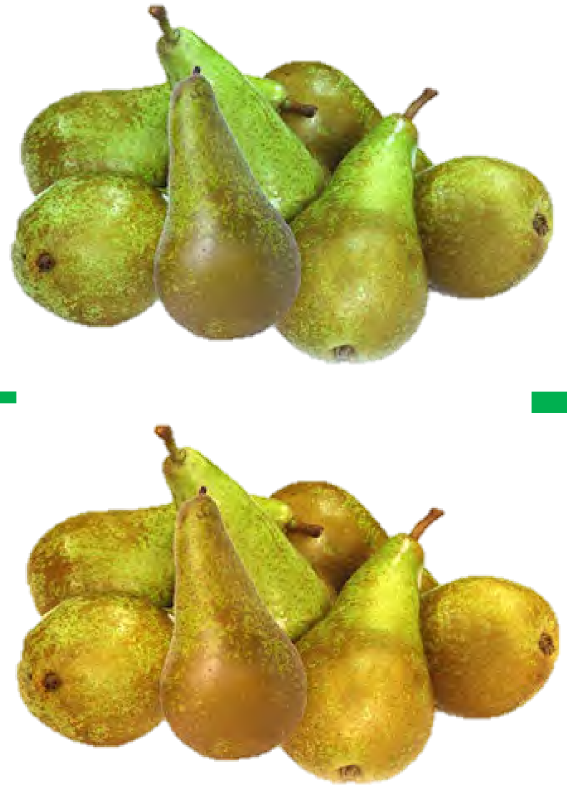
T

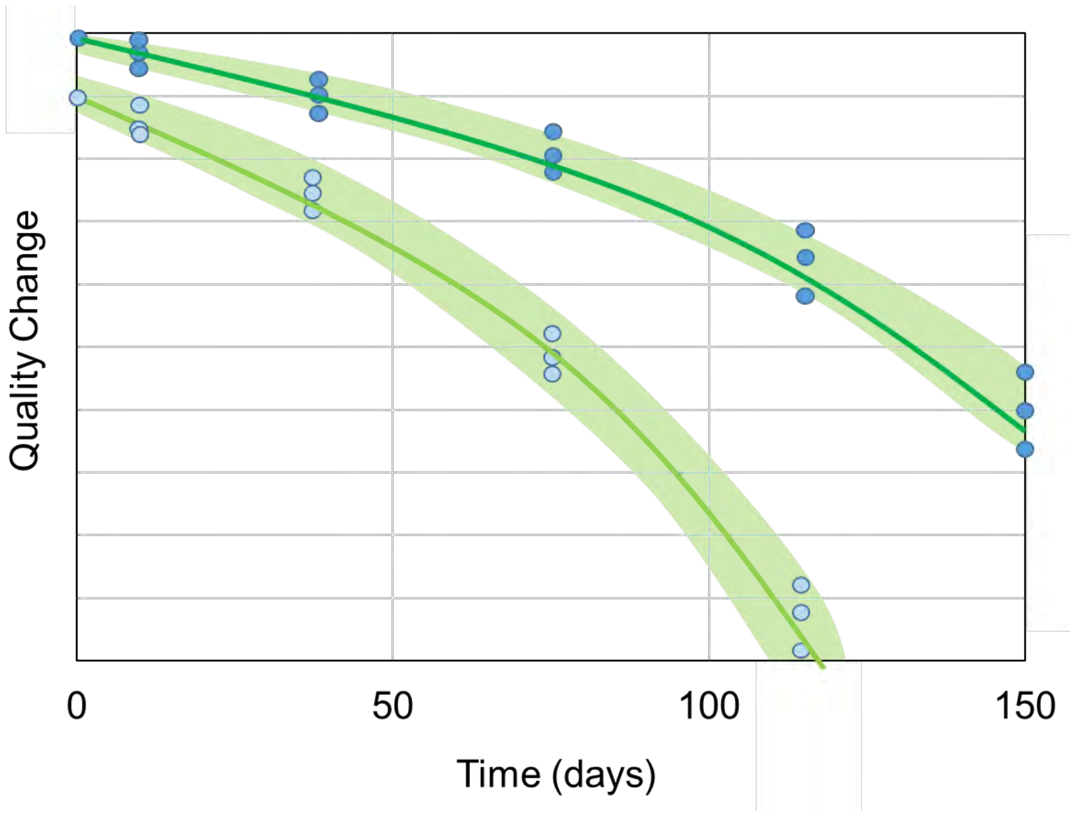
O_2

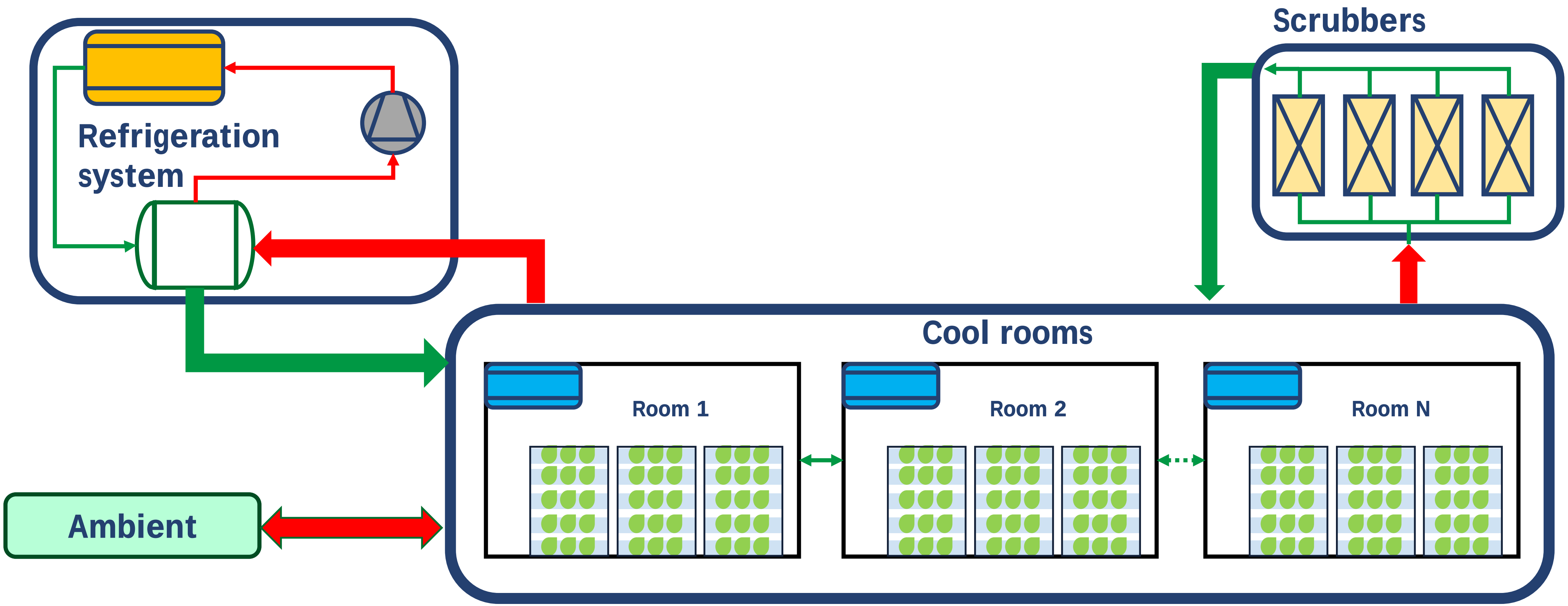
CO_2

C_2H_4

+

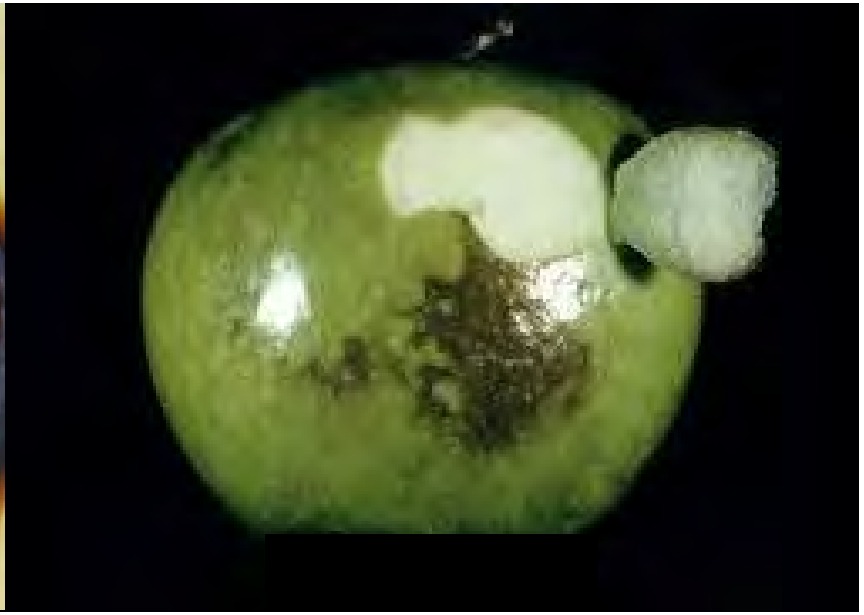





Scrubbers
Refrigeration system
Cool rooms
Room 1
Room 2
Room N
Ambient

Internal browning

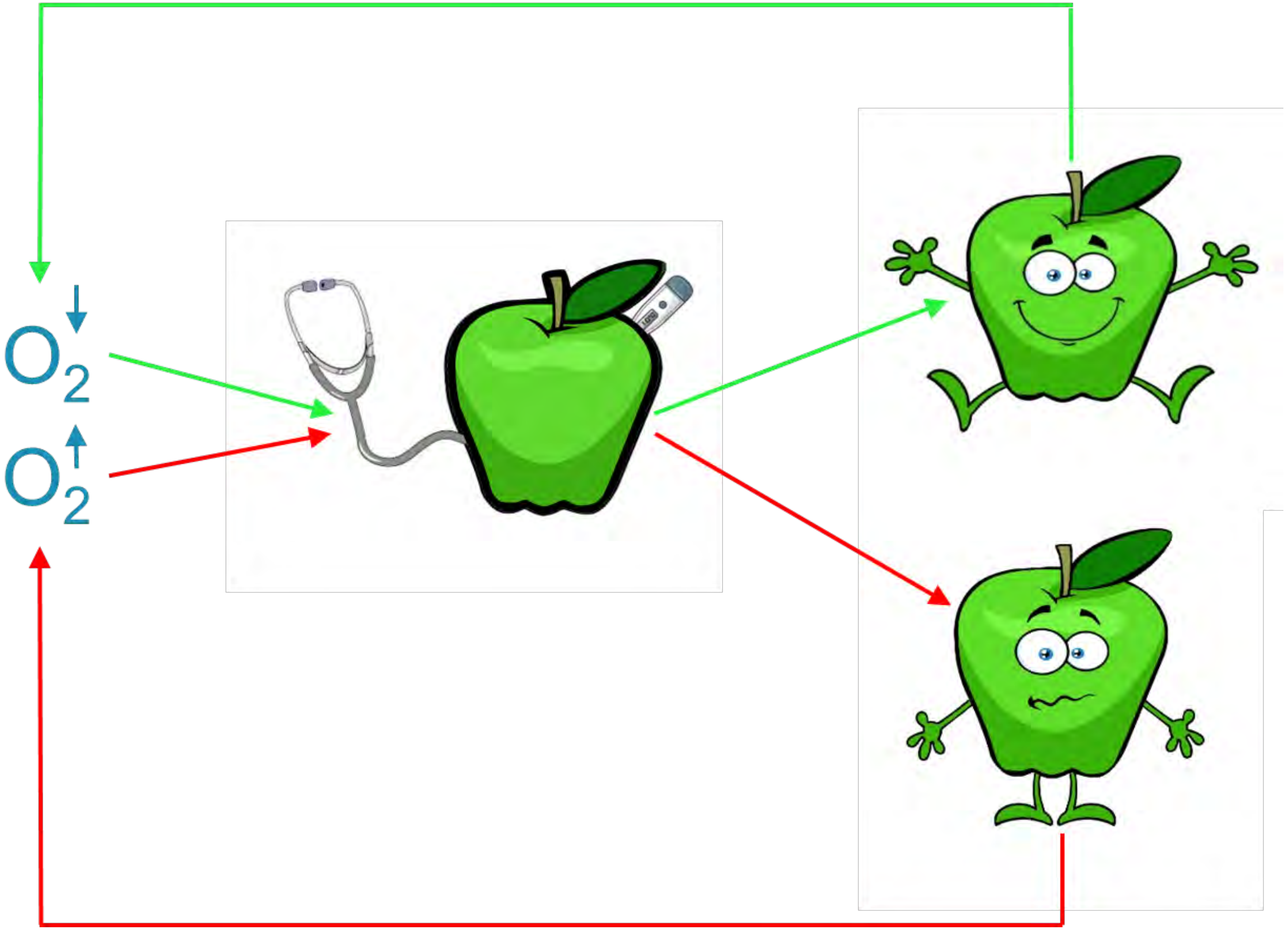
Superficial scald



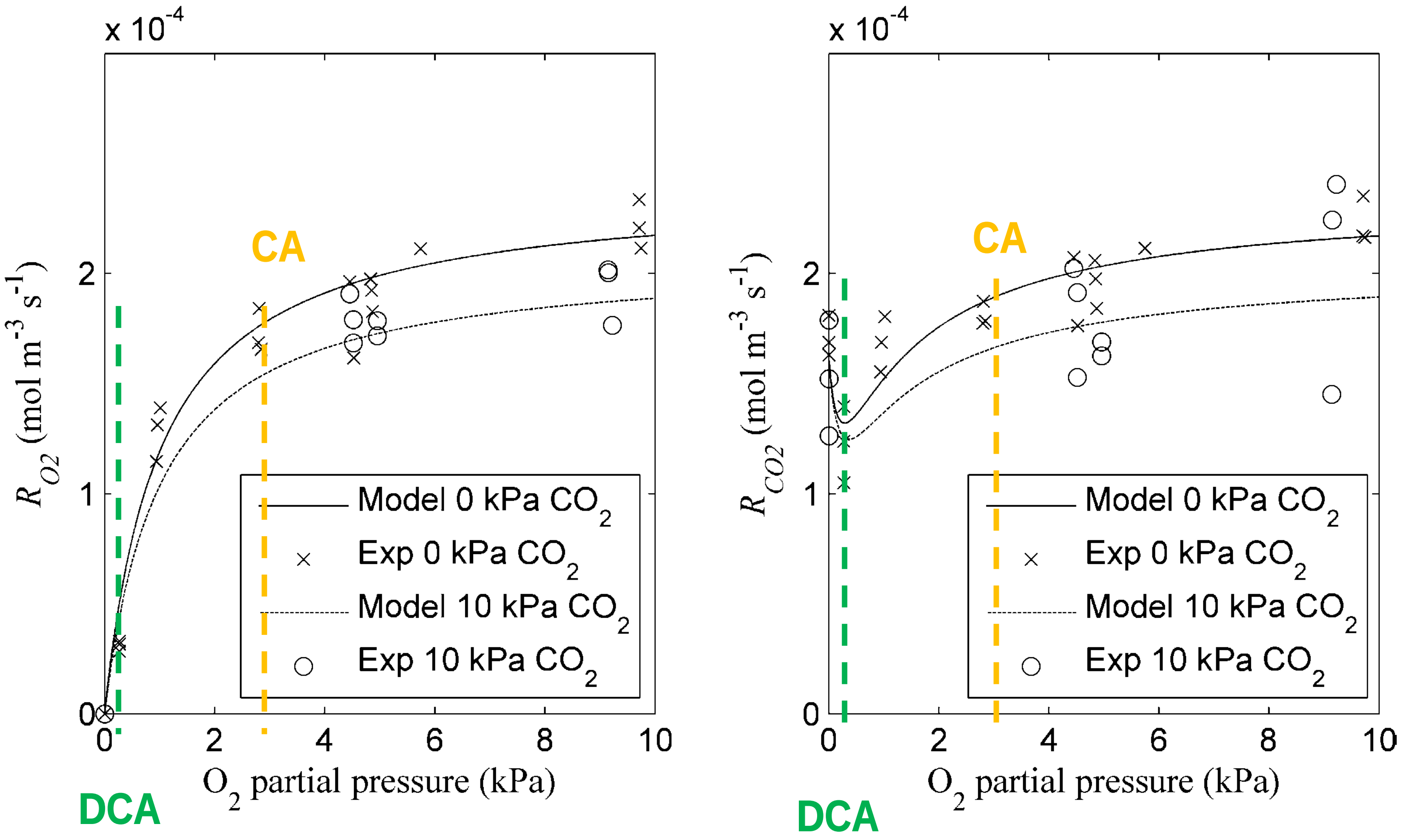
Too high oxygen

Too low oxygen

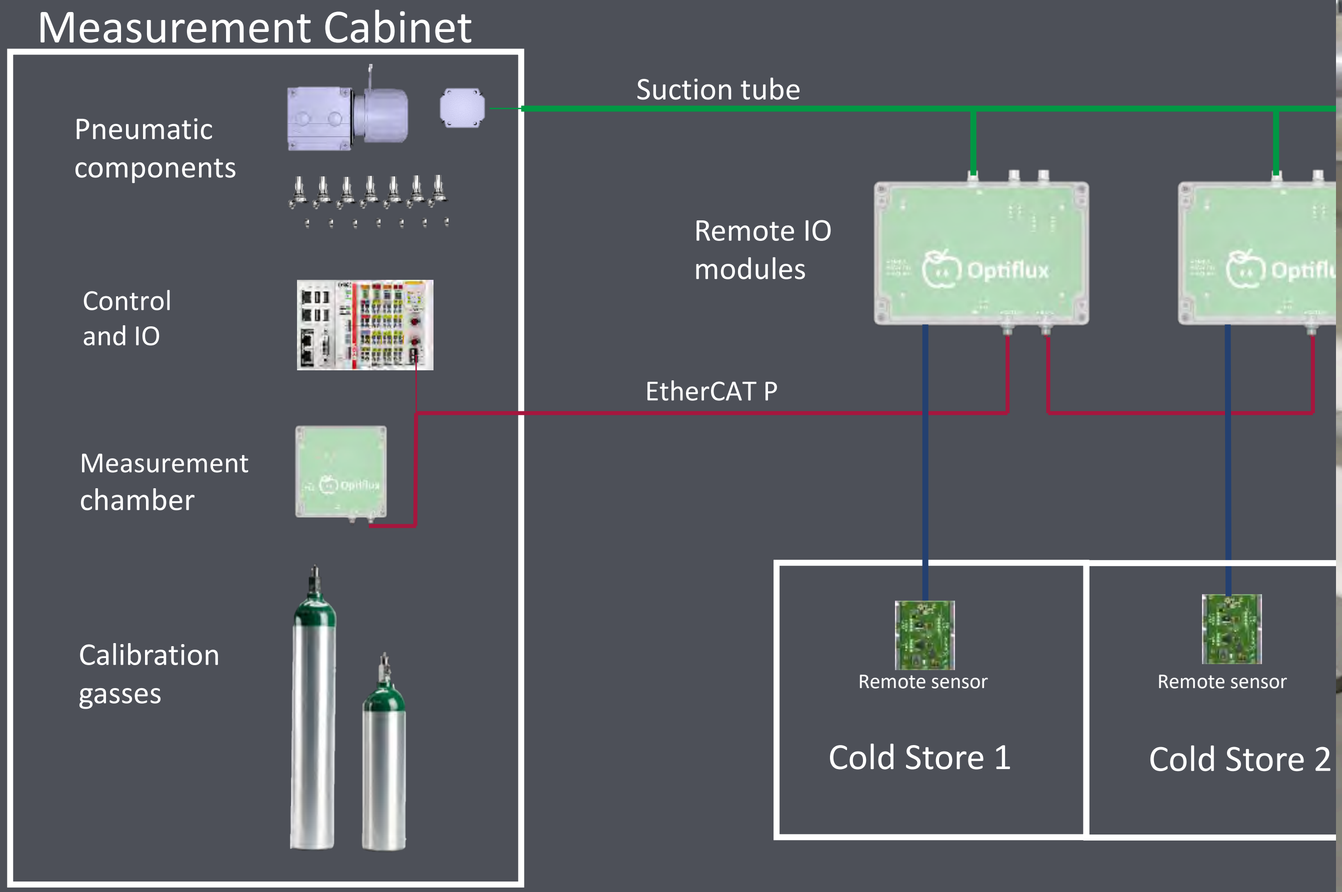
Dynamic controlled atmosphere (DCA)



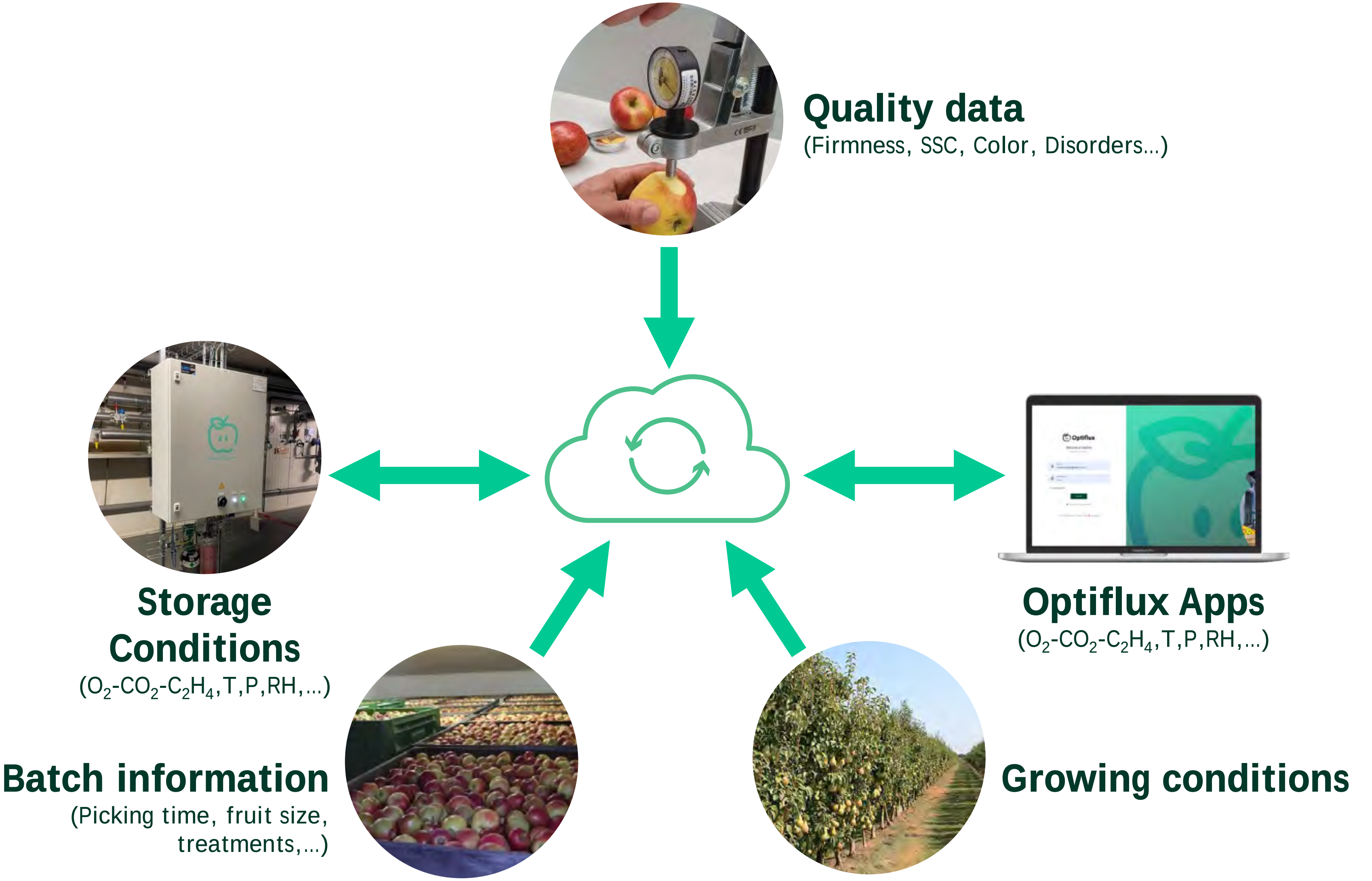
Respiration kinetics of pear fruit (cv. Conference)



DCA in practice: sensors+control unit



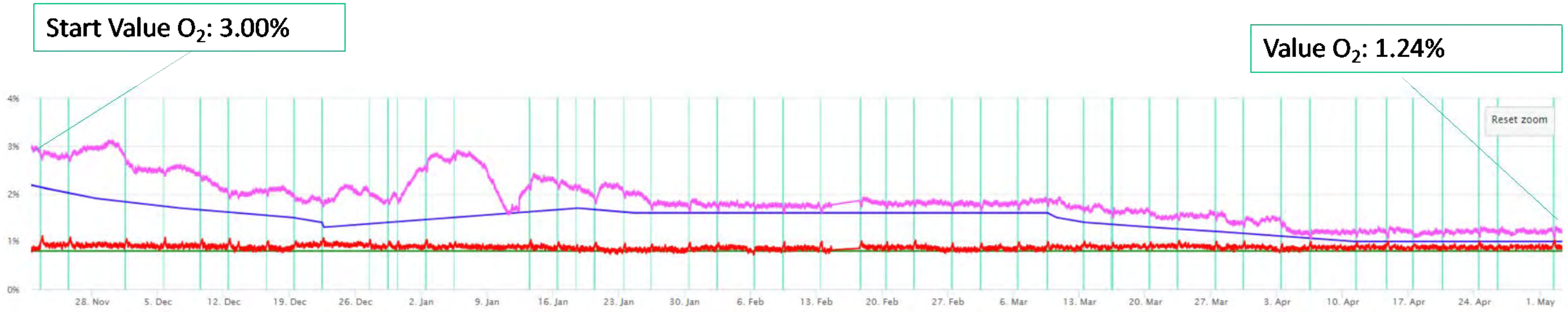
DCA in practice: cloud based data analytics



Optiflux

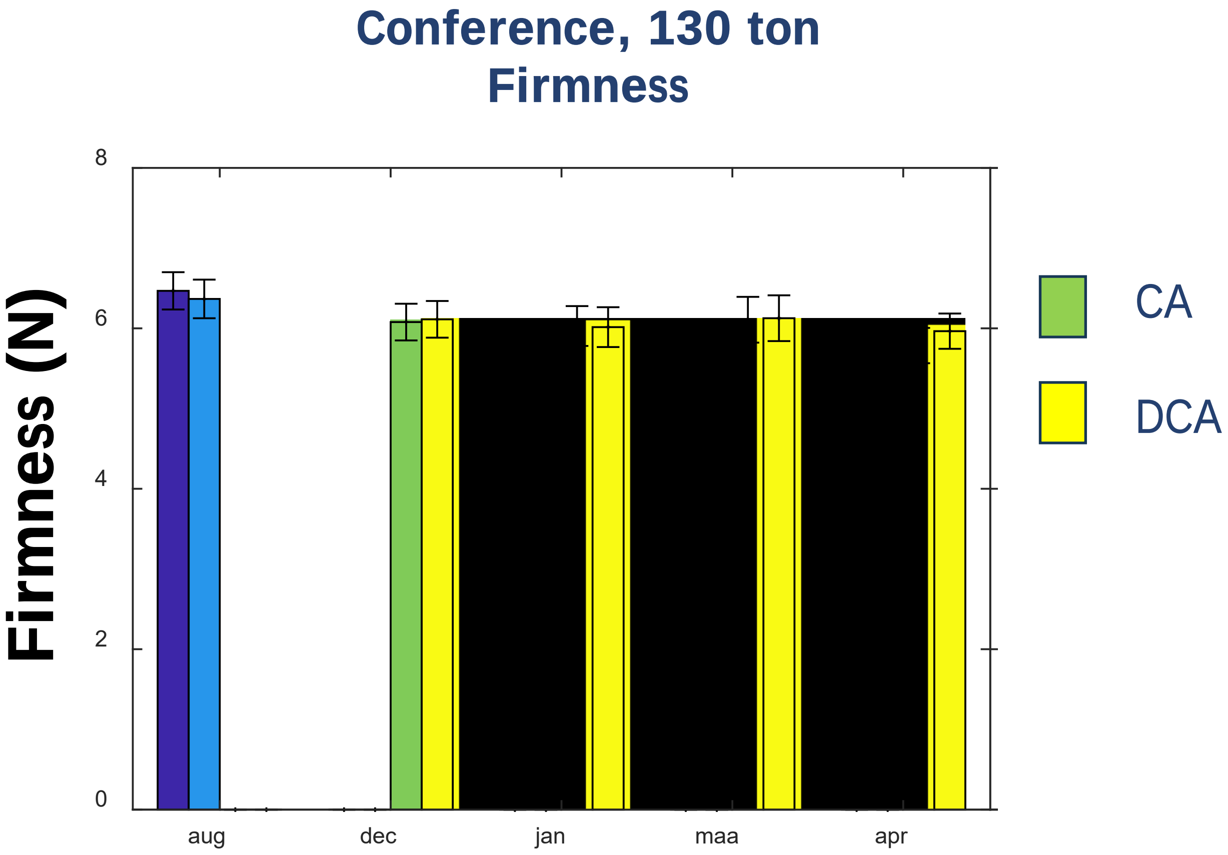
OptiControl™ DCA

Energy savings estimated 15% w.r.t standard CA

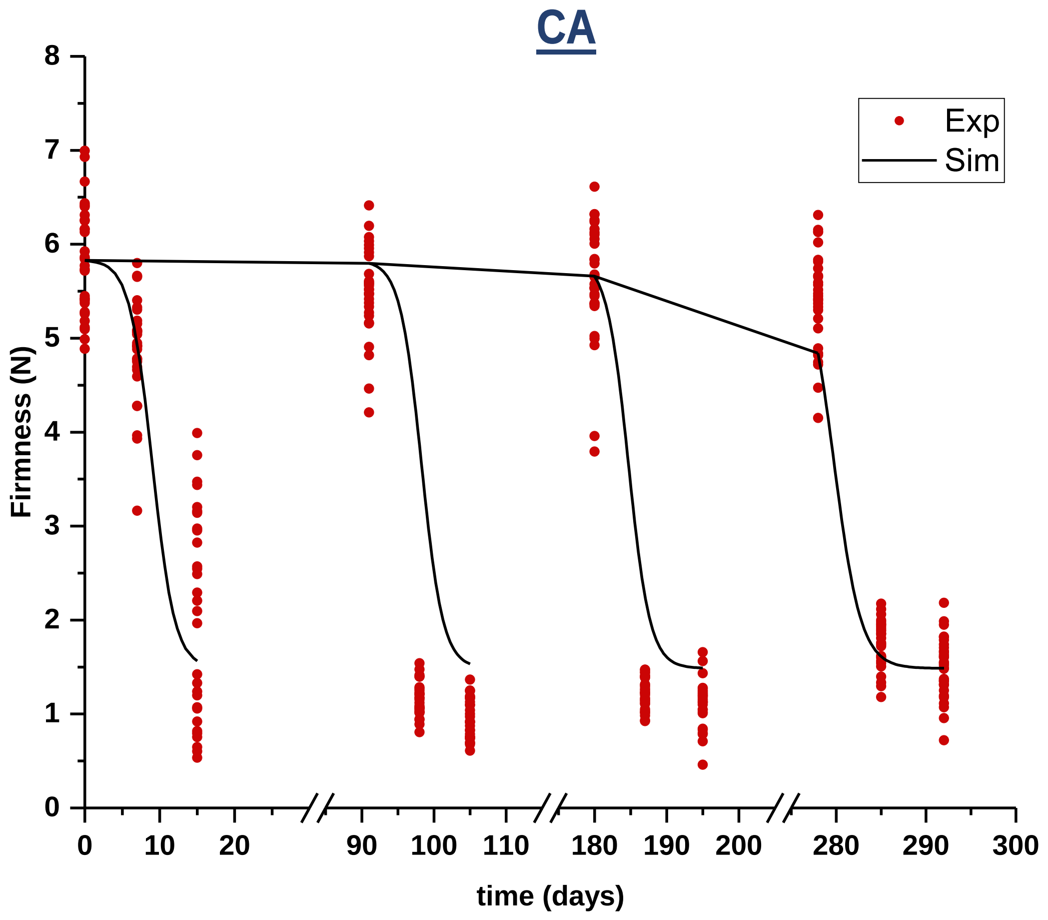


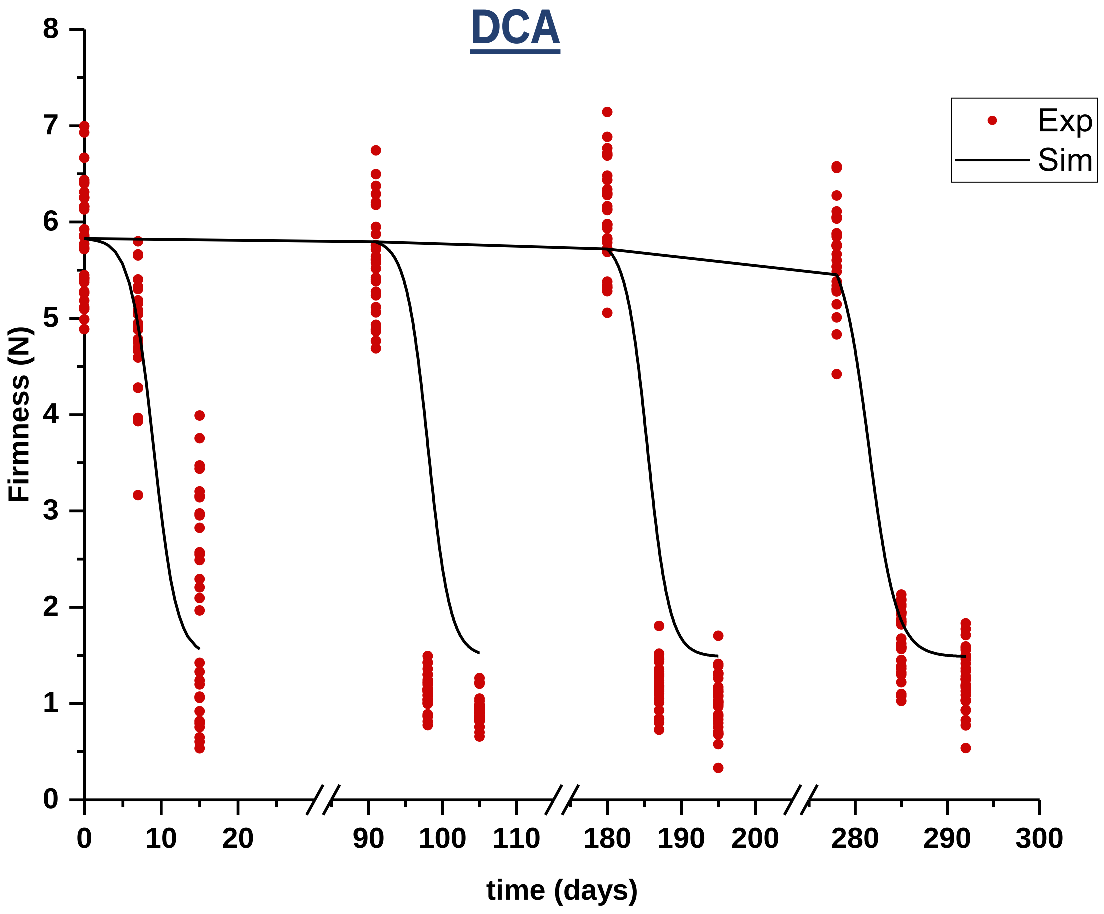
Optiflux

Quality measurement after DCA storage

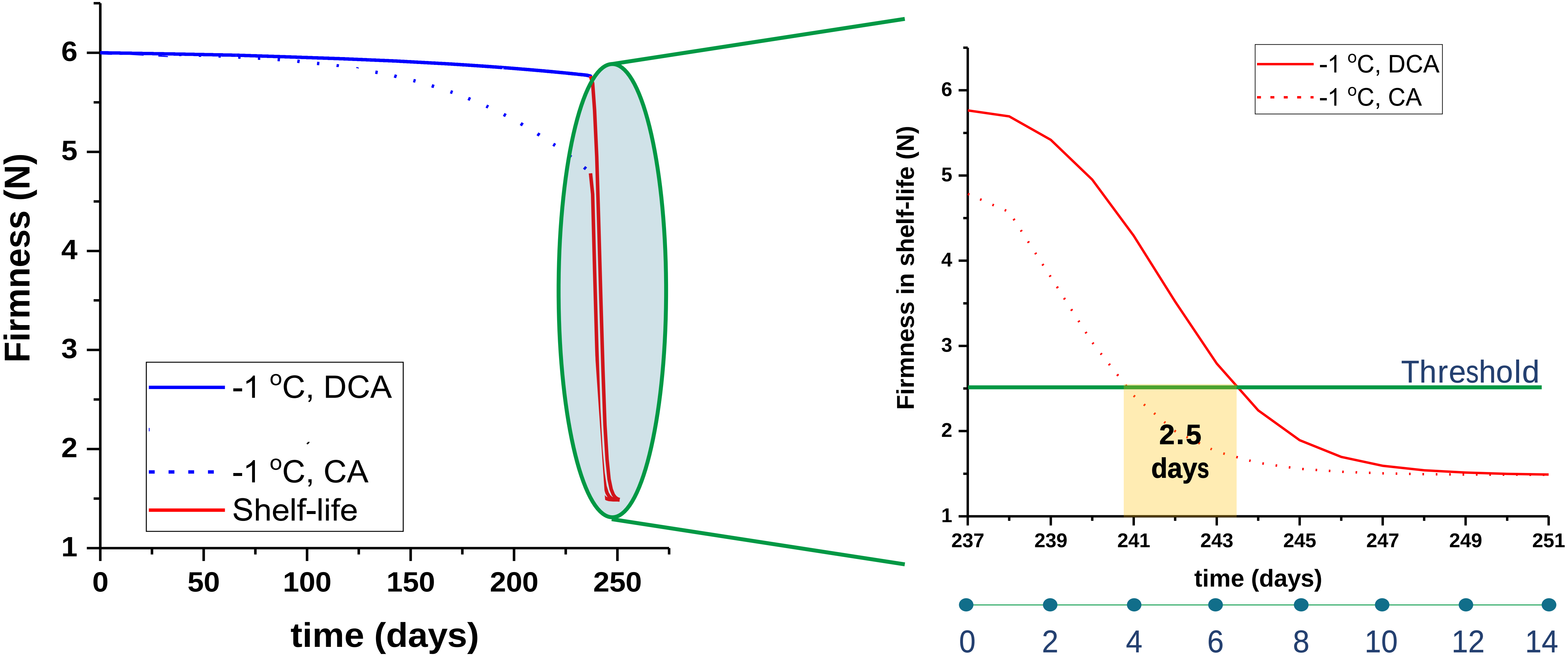


Quality kinetics modelling

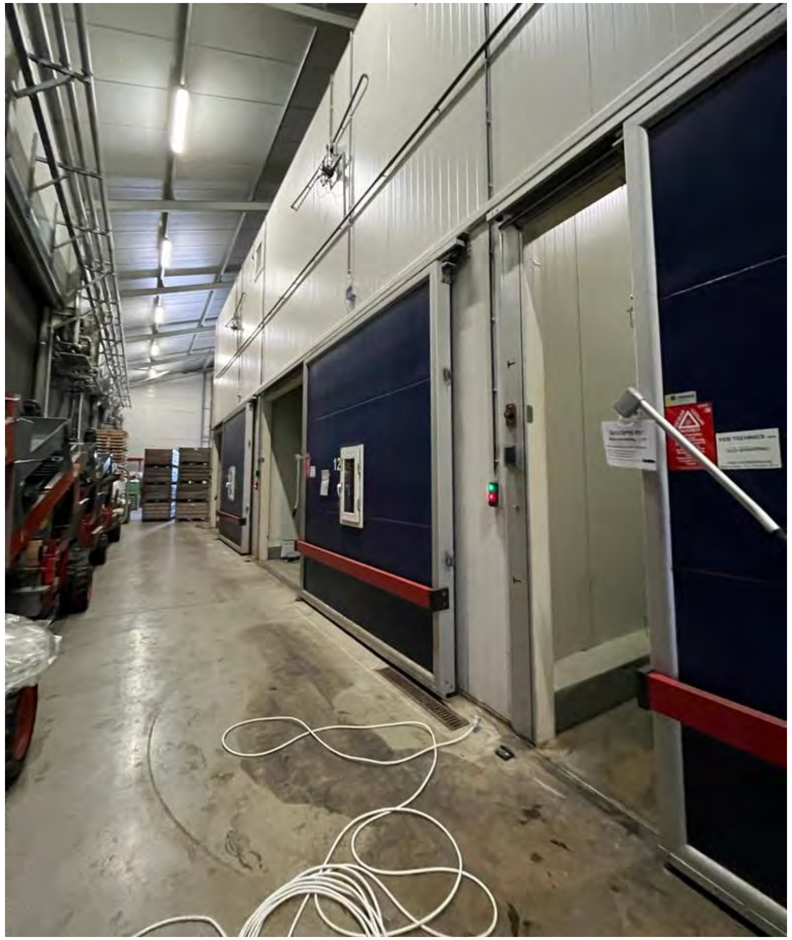


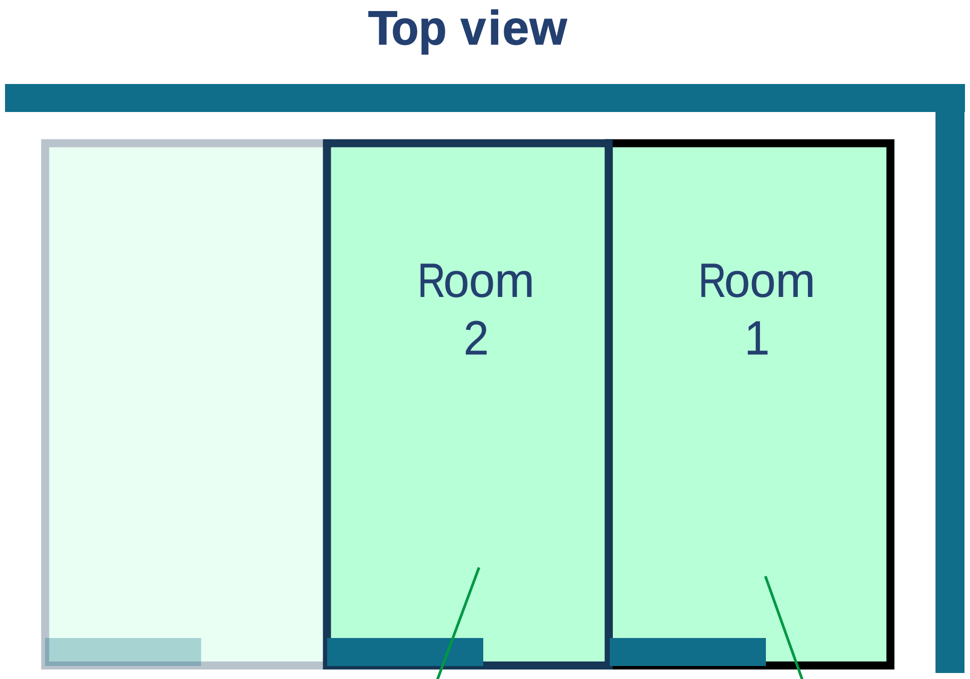


CA vs DCA quality



Validation experiment: pear storage and quality measurement





Info: Room 2
- CA condition
- Late harvest

Info: Room 1
- DCA condition
- Optimal harvest

Conclusions

- Observed effects of DCA
  - Control of disorders
    - Superficial scald
    - Internal browning
  - Improved quality after long term storage
    - Firmness, color
    - Also in shelf life
- DCA saves energy (expected 15%)
  - Less cooling for respiration heat
  - Less CO_2 scrubbing
  - Validation experiment underway

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Towards climate neutral packaging

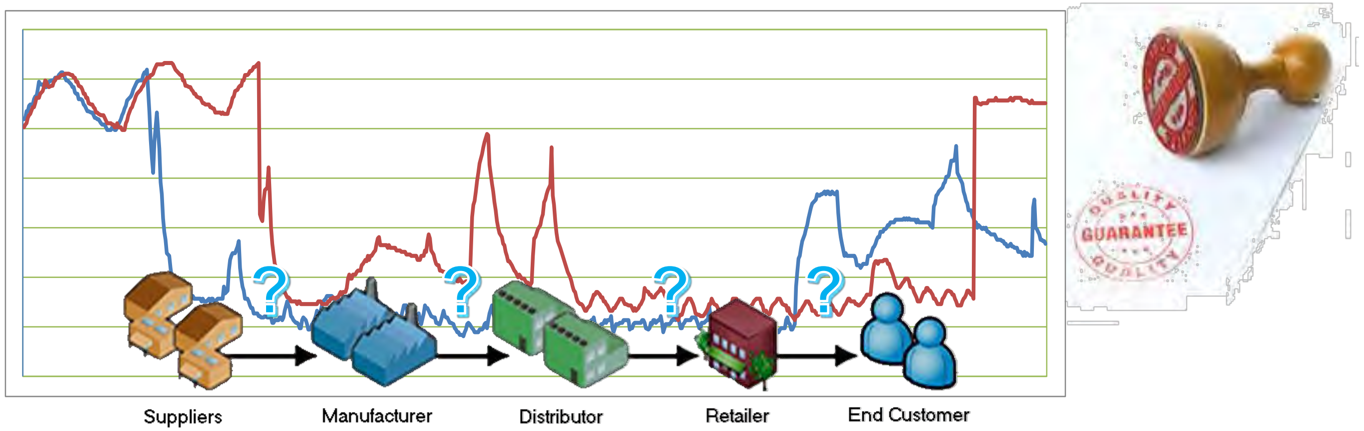
Maarten Hertog

KU LEUVEN

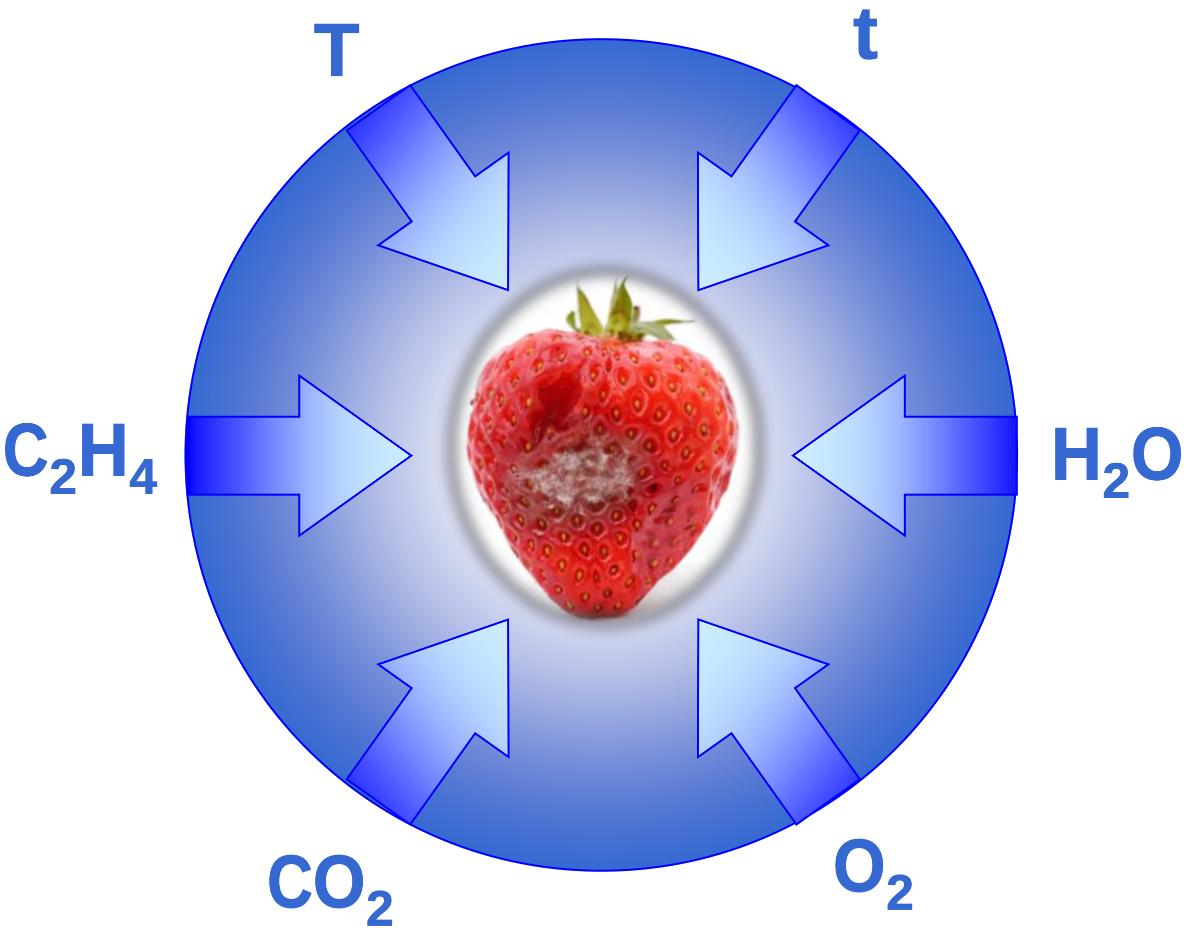
2023 WP6 Webinar
December 7, 2023
online

Postharvest chain

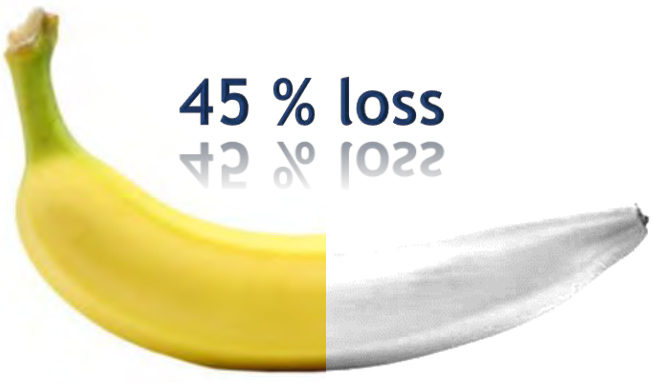
Rambutan

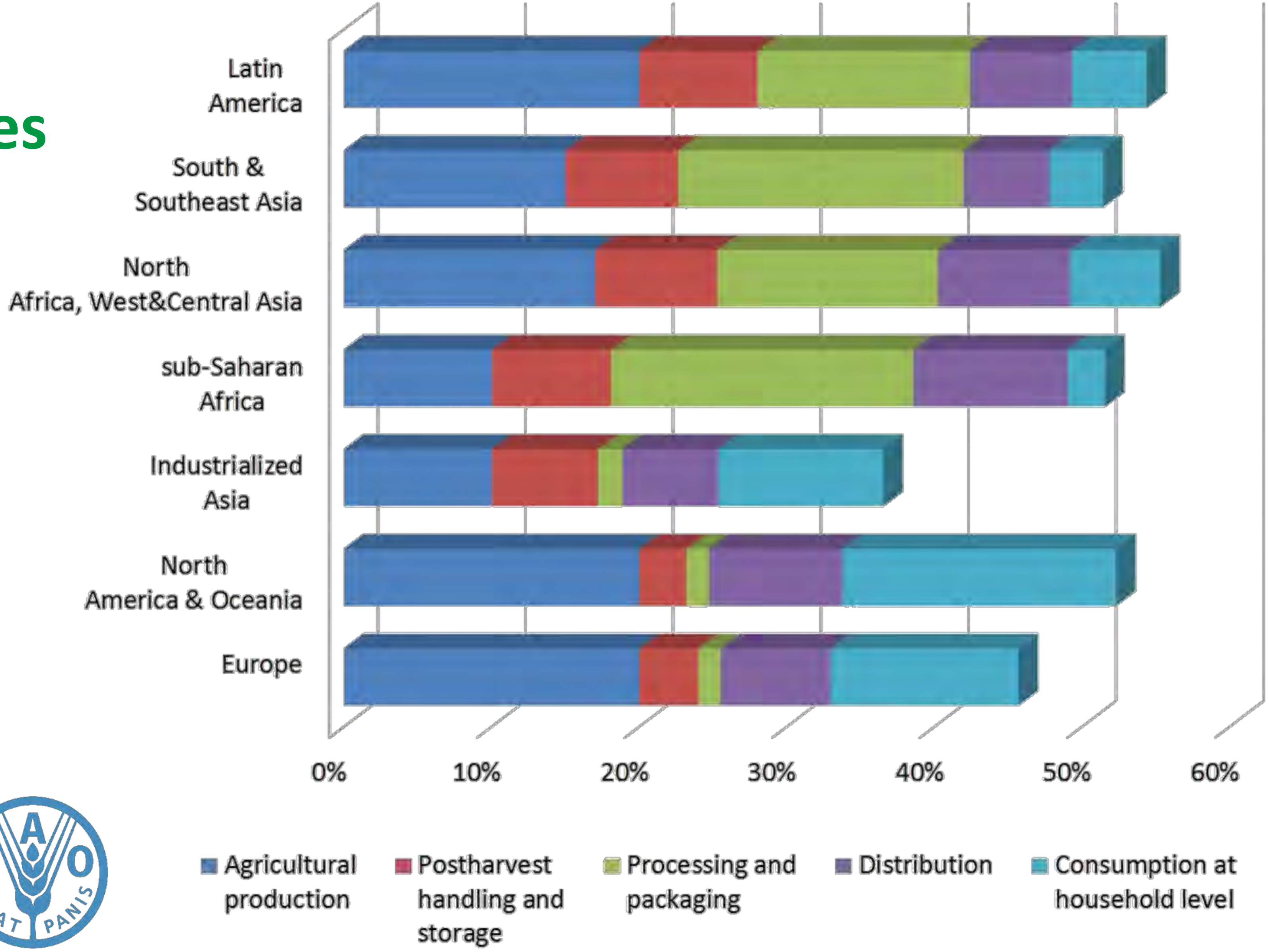


Perishable products



Postharvest losses





data taken from www.fao.org/docrep/014/mb060e/mb060e00.pdf

Food chain packaging

Bulk packaging

Primary packaging

Secondary packaging

Package stacking

Containerisation

Sustainable initiatives

Food chain packaging

Bulk packaging

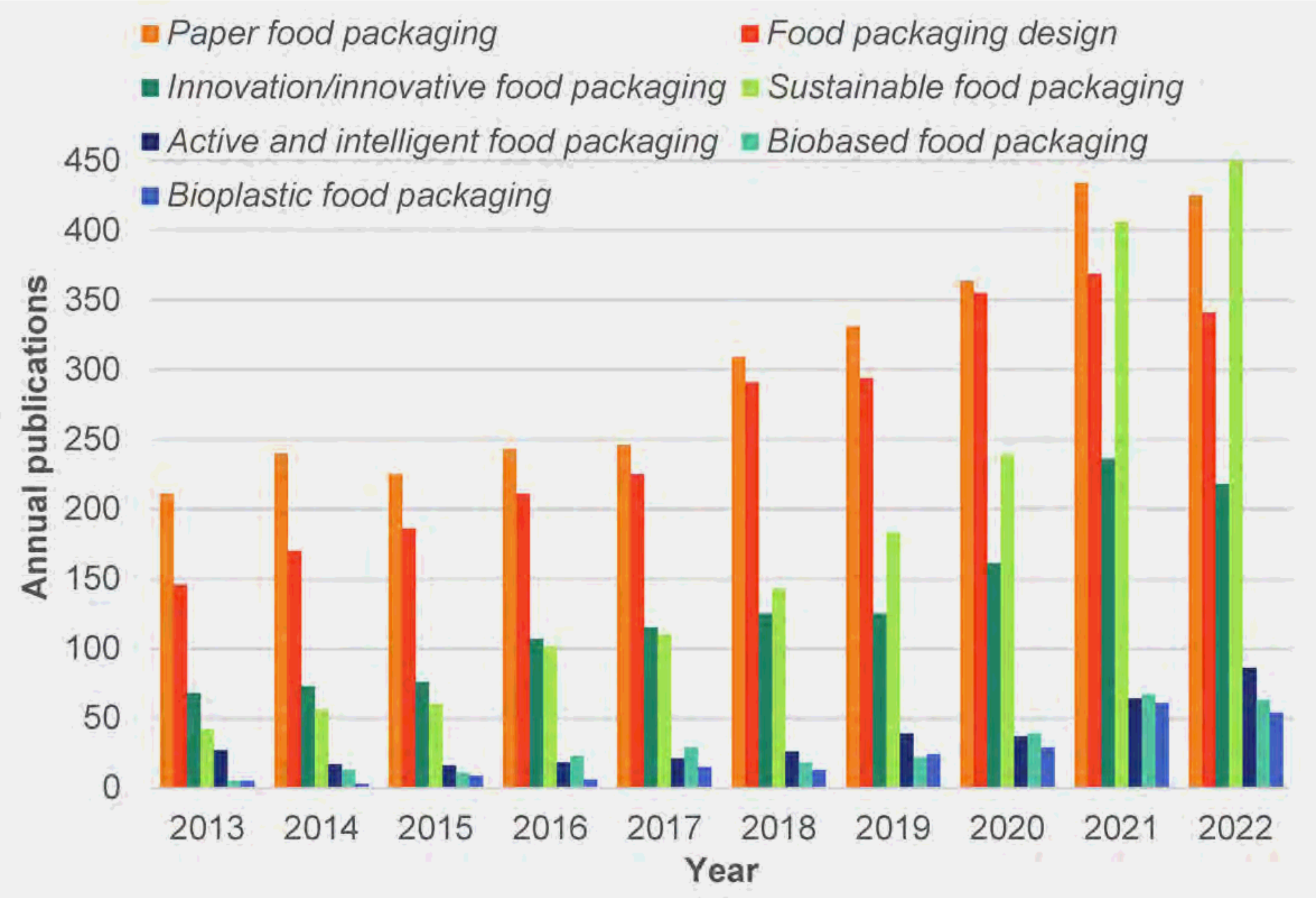
Primary packaging

Secondary packaging

Package stacking

Containerisation

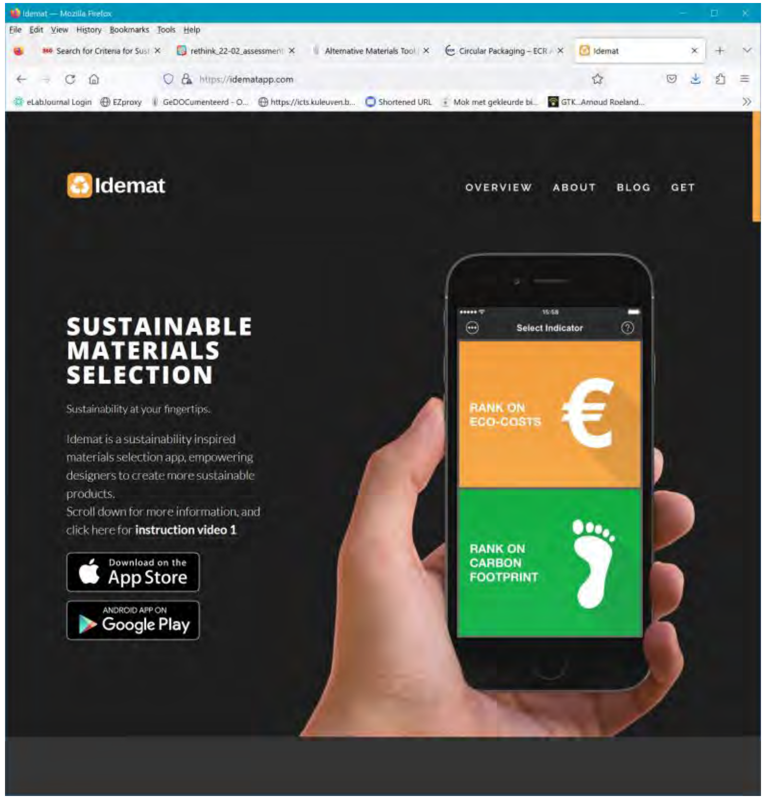
Sustainable initiatives

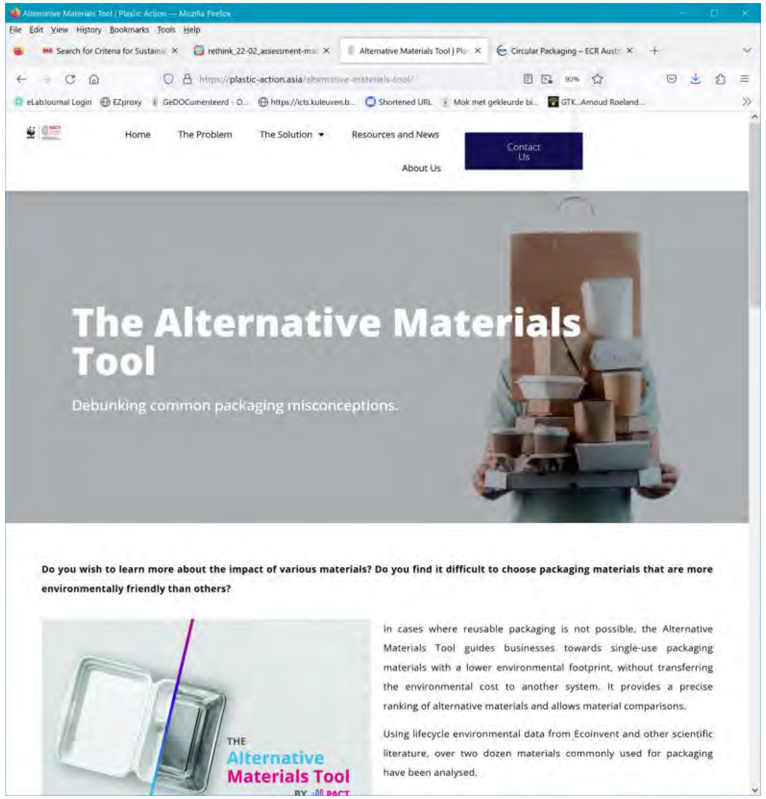


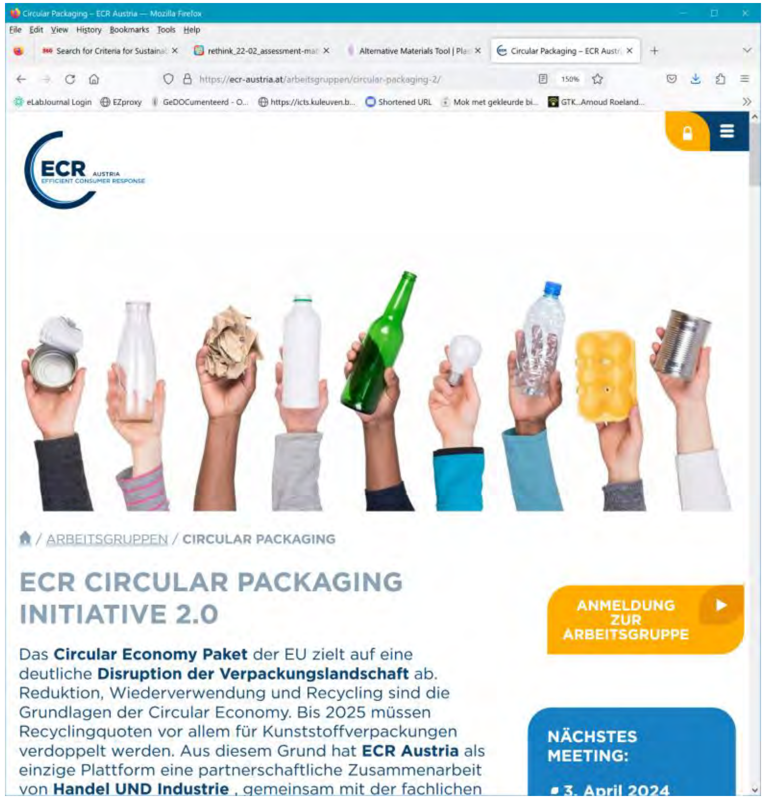
https://doi.org/10.3390/foods12051057

Sustainable initiatives

Assessing sustainability of packaging

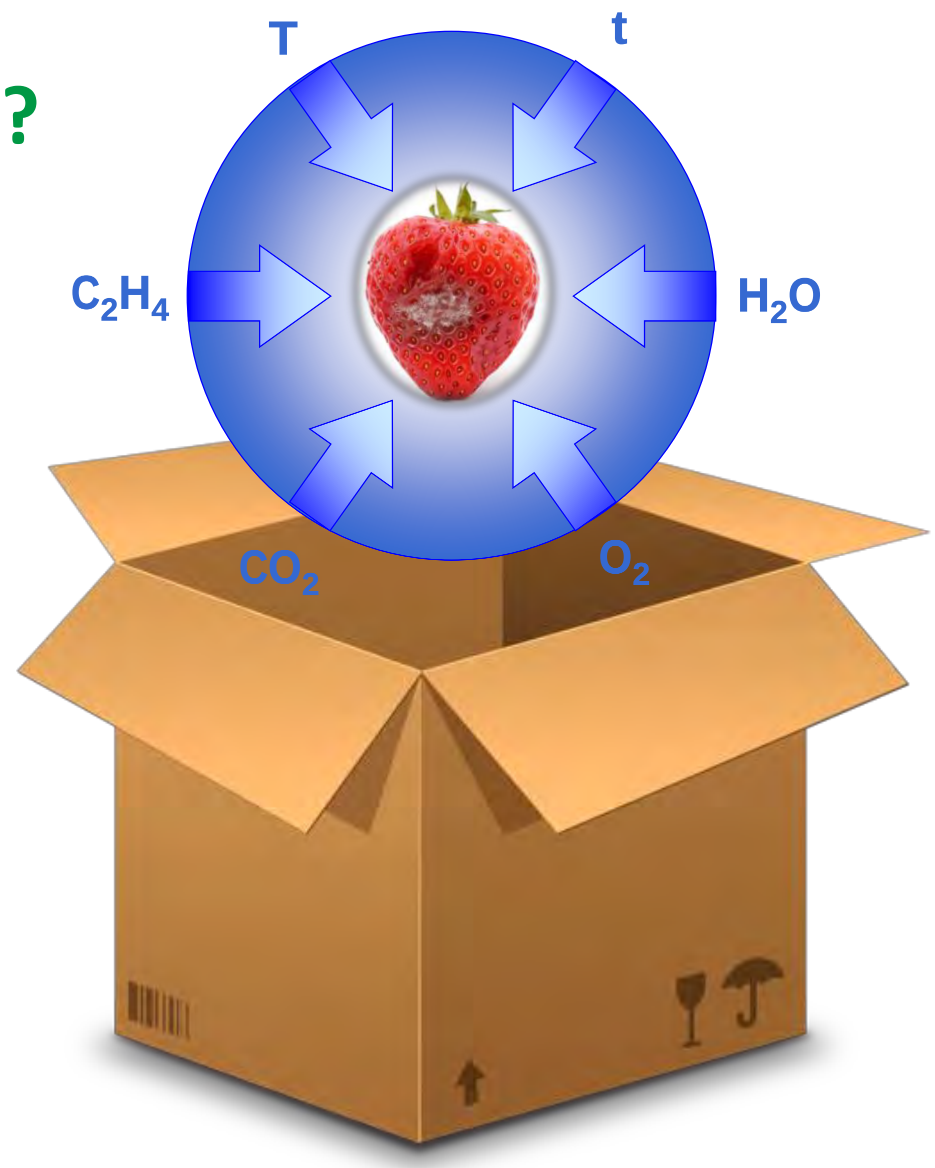






What about food (quality) losses?

- Climate neutral packaging
  - √ Packaging materials
  - √ Reducing waste
  - √ Maintaining quality



Consumer packages soft fruit

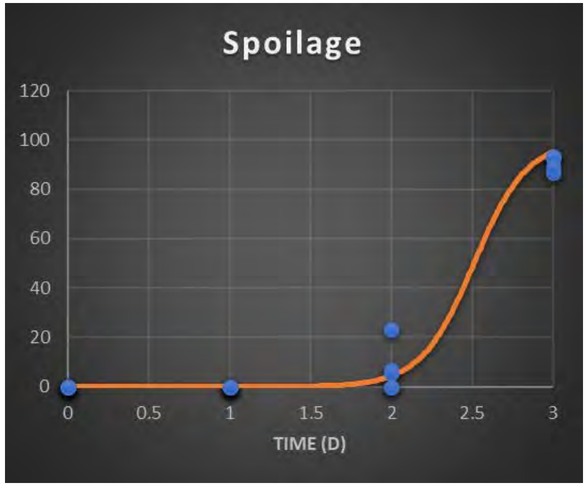
Quality attributes

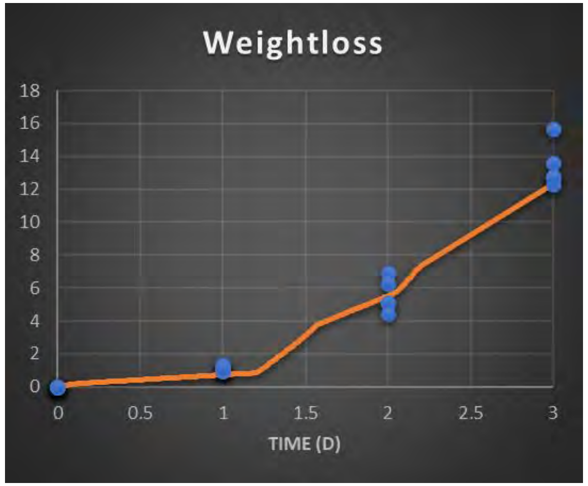
- Weight loss
- Microbial decay

Main influential factors

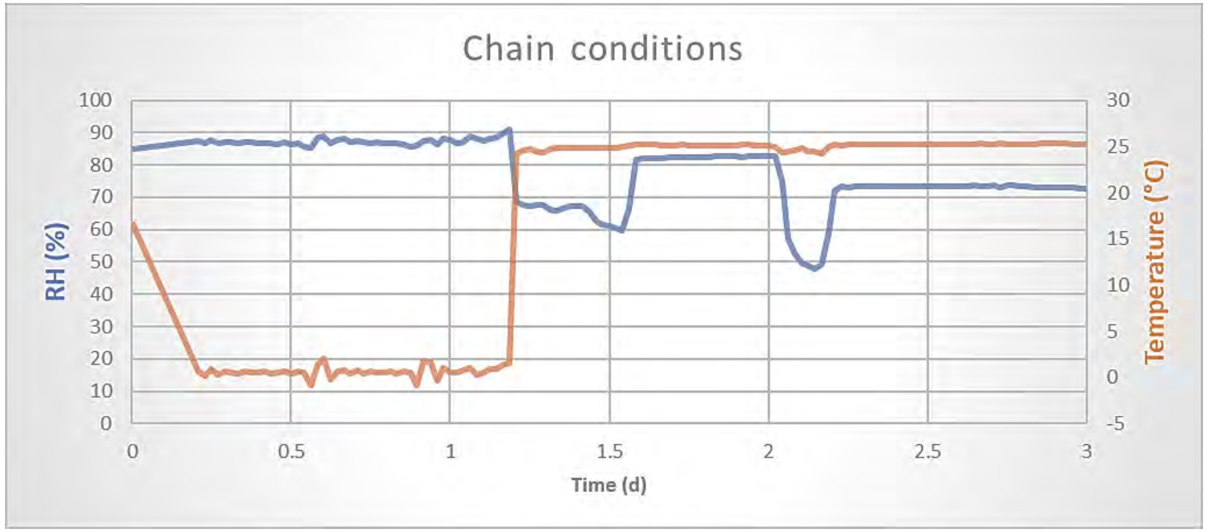
- Time
- Temperature
- RH
- CO_2
- Batch variation

Current practices





eit Food DigiFresh



Main challenges

- Identifying viable alternatives
- Material compatibility
  - Technical
  - Food wise
- Involving industries with trials

Consumer packages soft fruit

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Fresh and Green Delivery

Francesco Fabris

Consiglio Nazionale delle Ricerche – Istituto per le Tecnologie della Costruzione (CNR-ITC)

ITC

How to improve the sustainability of the food chain?
ENOUGH webinar, 07/12/2023

CHALLENGES

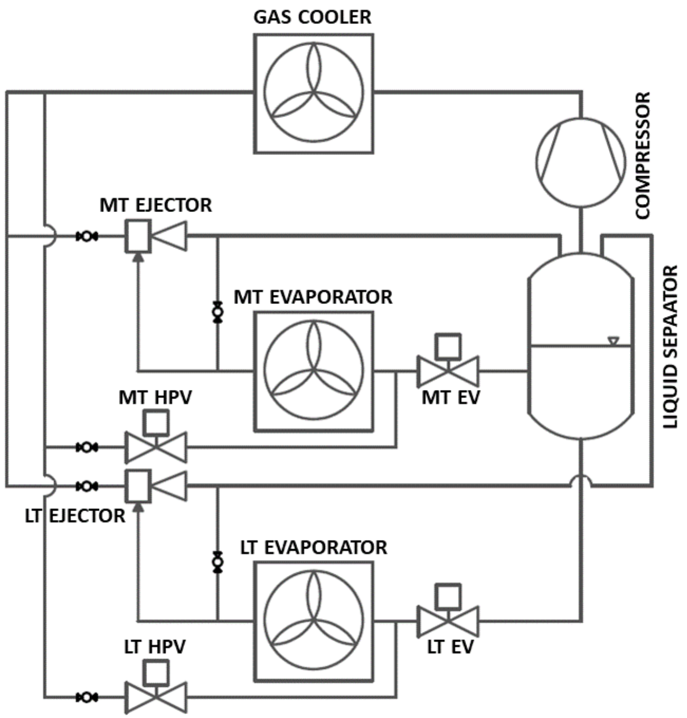
- Context:
  - The cold chain is responsible of around 4% of the overall global emissions.
  - Refrigerated transport is a key link to preserve the cold chain and avoid food losses.
  - The IIR estimated that the global refrigerated fleet in 2021 consisted in 3.4 M vehicles, representing nearly 25% of the total cold chain emissions.
- Challenges:
  - Current transport refrigeration units are not optimized, present low efficiency and employ synthetic refrigerants (such as HFCs and HFOs), characterized by negative environmental impacts.
  - Achieving more flexibility in the logistics, reducing the number of vehicles on the road, especially for last mile delivery in urban environment, and facing the progressive ban of synthetic refrigerants following the EU F-Gas Regulation represents the major challenge.

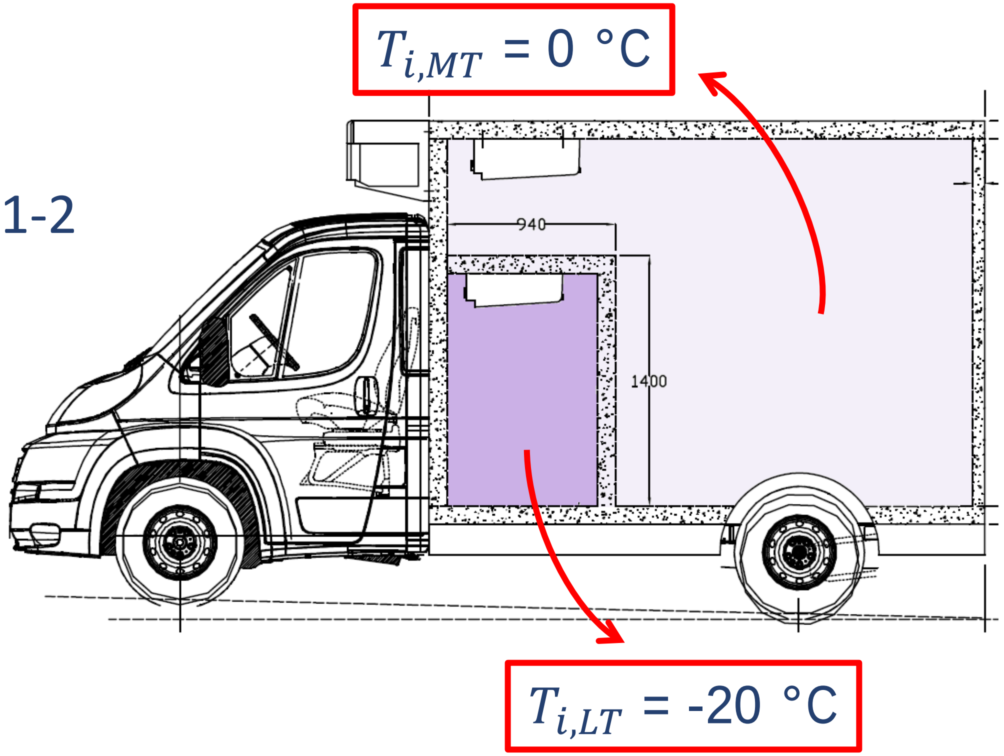
OBJECTIVES

- Objectives:
  - Development of a transport refrigeration unit with high efficiency, leading to significant reduction of energy consumption and emissions.
  - Use of natural refrigerants with zero or negligible environmental impact.
  - Realization of a system allowing flexibility in the temperature range of the transported products.
  - Use of an electric vehicle to avoid fossil fuel consumption for traction.
  - Integration of renewable energy sources providing positive contribution to the overall refrigerated vehicle energy balance.

APPLICATION AND CYCLE DEFINITION

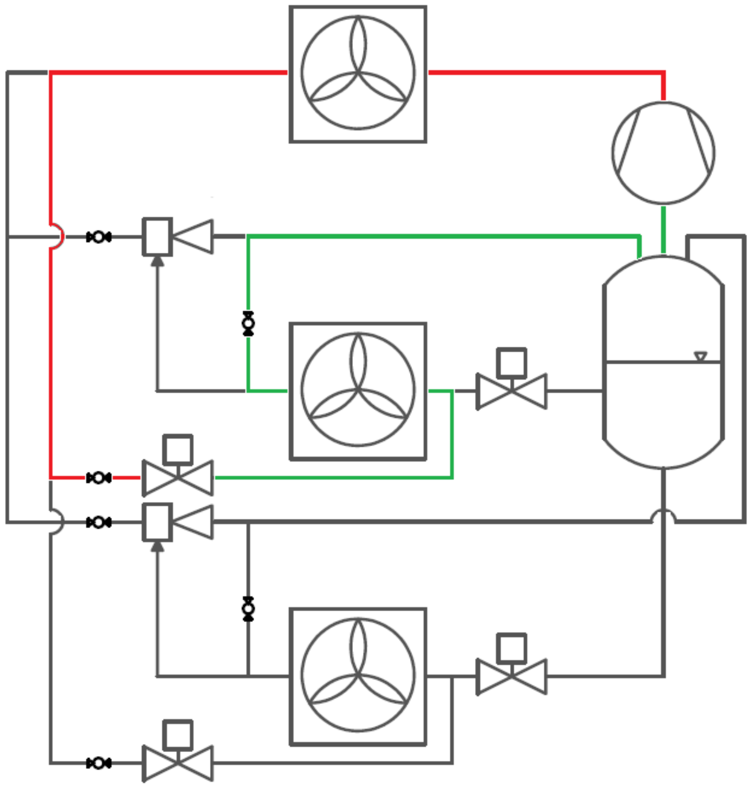
- CO_2 unit for multi-temperature road transport refrigeration applications.
- Design cooling power: 4-5 kW MT (0°C); 1-2 kW LT (-20°C).



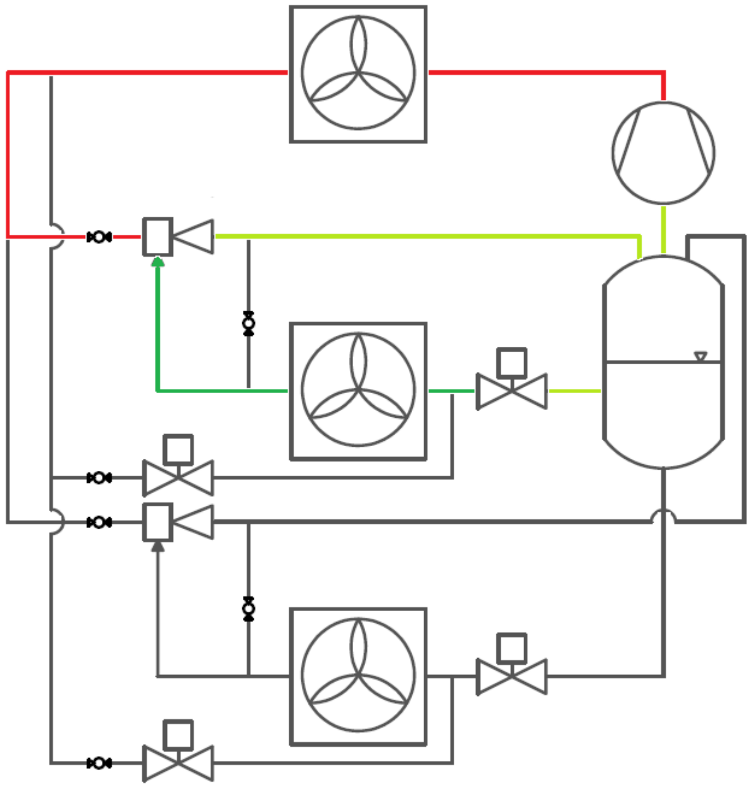


- Single-compression dual-temperature unit; back-pressure or ejector configuration for both MT and LT operation.

SYSTEM CONFIGURATIONS



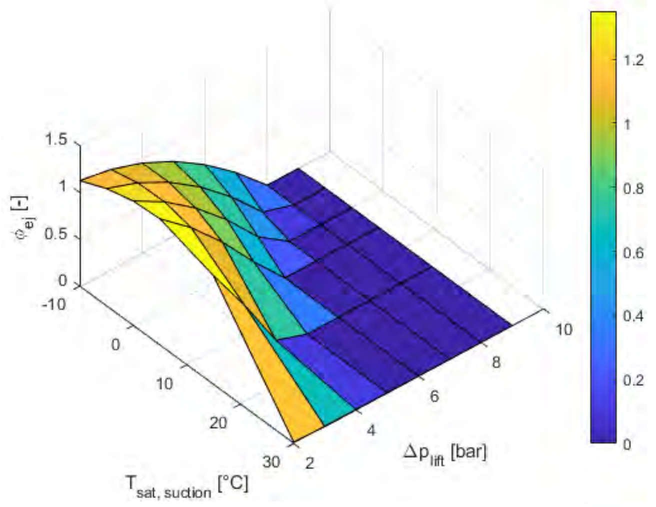
MT back-presure cycle



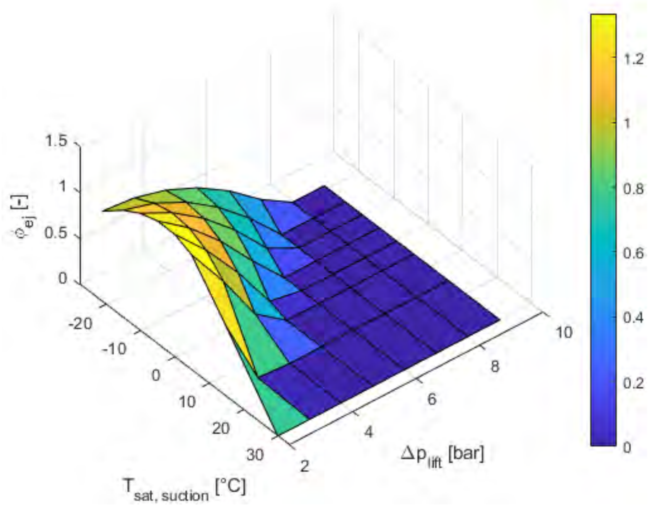
MT ejector cycle

EJECTORS DESIGN AND PERFORMANCE

- Specific design process of MT and LT ejectors; characteristic dimensions optimized to provide the design cooling power in rated conditions:
  - MT ejector throat diameter: 0.95 mm;
  - LT ejector throat diameter: 0.46 mm.
- CFD-based numerical simulations carried out to assess the performance of the ejectors (entrainment ratio, efficiency).
- Performance maps of the ejectors obtained through interpolation of the numerical results.
- Ejectors prototypes have been commissioned and manufactured.



MT ejector



LT ejector

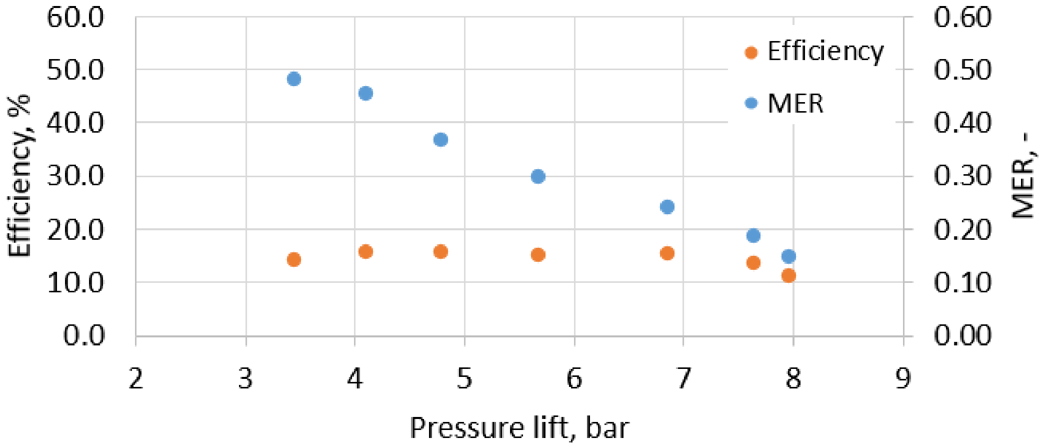
(for T_{motive} = 35°C, p_{motive} = 86 bar)

EXPERIMENTAL TESTS ON EJECTORS

- Ejectors prototypes have been experimentally tested in SUT laboratories.
- Experimental results show good performance of both MT and LT ejector.

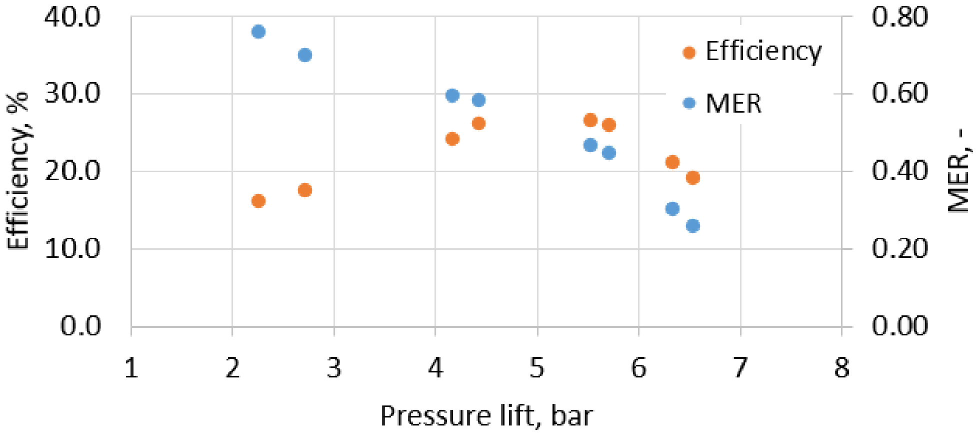
MT EJECTOR

(p_{motive} = 86 bar, $p_{suction}$ = 26 bar)



LT EJECTOR

(p_{motive} = 86 bar, $p_{suction}$ = 22.5 bar)



EXPERIMENTAL TESTS ON EJECTORS

- However, for specific operating conditions, in both cases the experimental mass flow rate at the motive nozzle is slightly higher and the entrainment ratio is slightly lower than the “design” one.

MT EJECTOR

	p_{motive} [bar]	T_{motive} [°C]	$\dot{m}_{motive}$ [kg/s]	$p_{suction}$ [bar]	Δp_{lift} [bar]	ϕ_{ej} [-]
DESIGN	86	36	0.0316	26	4	0.535
EXP.	86	36	0.0371 +17.4%	26	4	0.456 -14.7%

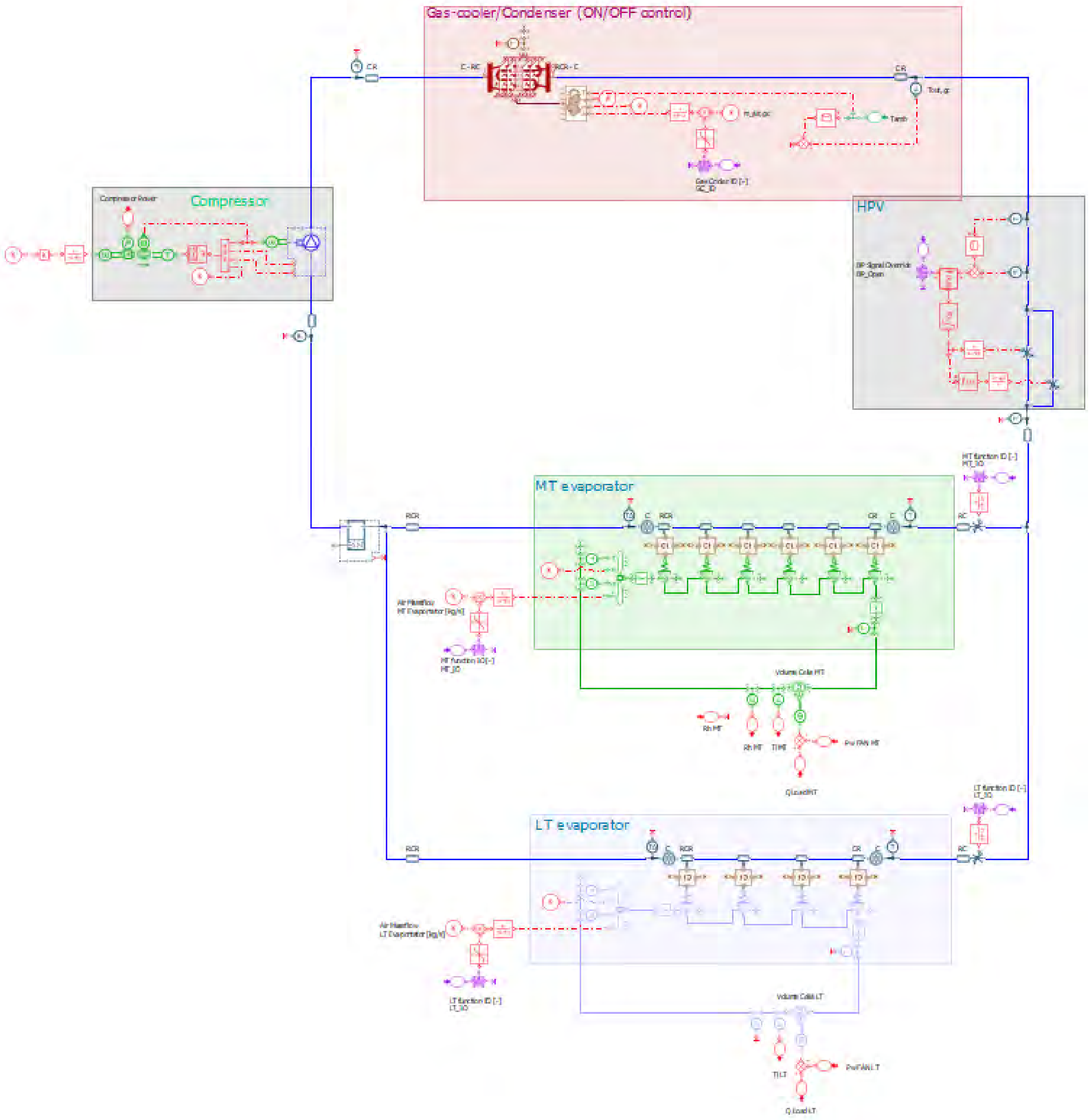
LT EJECTOR

	p_{motive} [bar]	T_{motive} [°C]	$\dot{m}_{motive}$ [kg/s]	$p_{suction}$ [bar]	Δp_{lift} [bar]	ϕ_{ej} [-]
DESIGN	86	36	0.00767	15	4	0.449
EXP.	86	36	0.00839 +9.4%	22.5*	4	0.583*

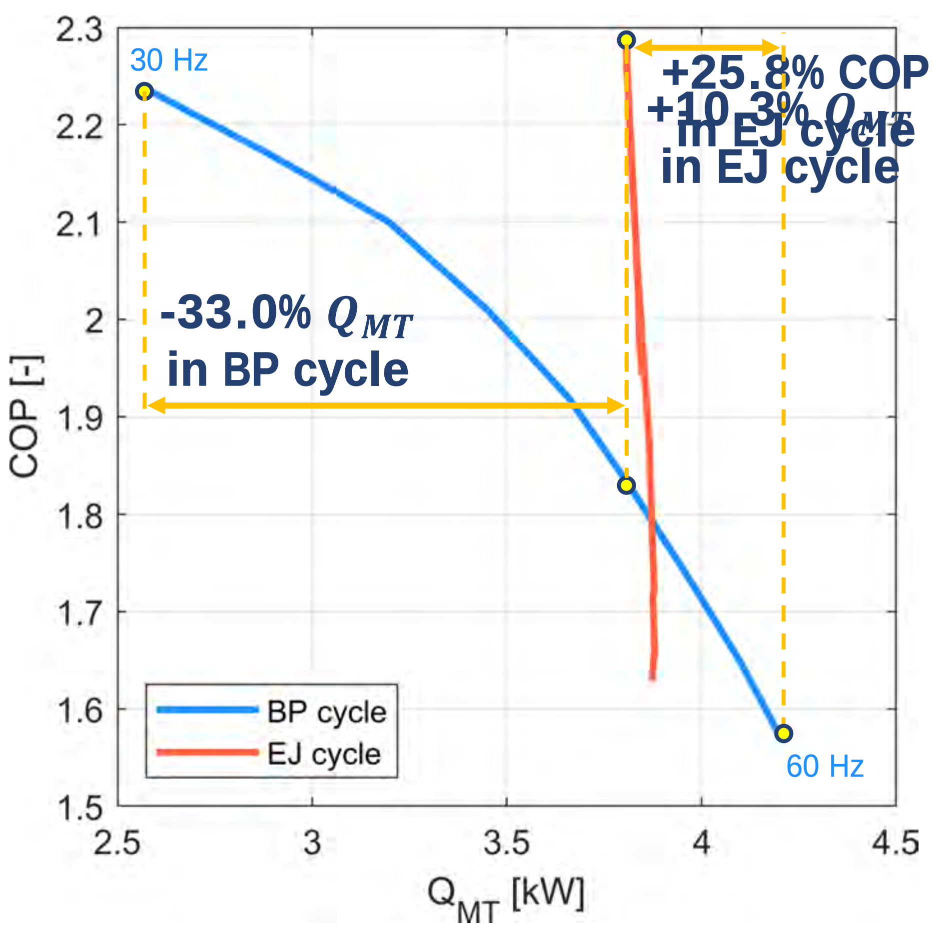
*different suction conditions

NUMERICAL MODELLING

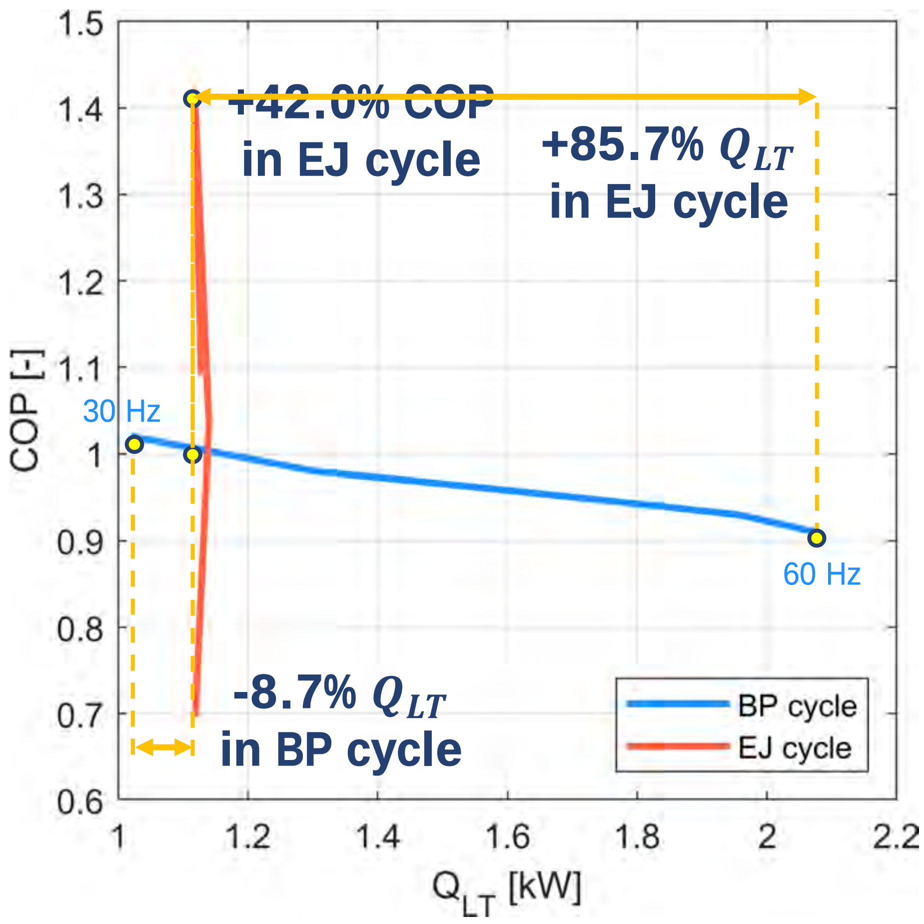
- Dynamic numerical model of the cooling unit.
- Discretization of real components in lumped parameters elements connected to describe the system.
- Each element is described by nonlinear time-dependent differential equations, integrated over time.
- Steady-state and dynamic performance evaluation of the unit.



STEADY-STATE NUMERICAL RESULTS



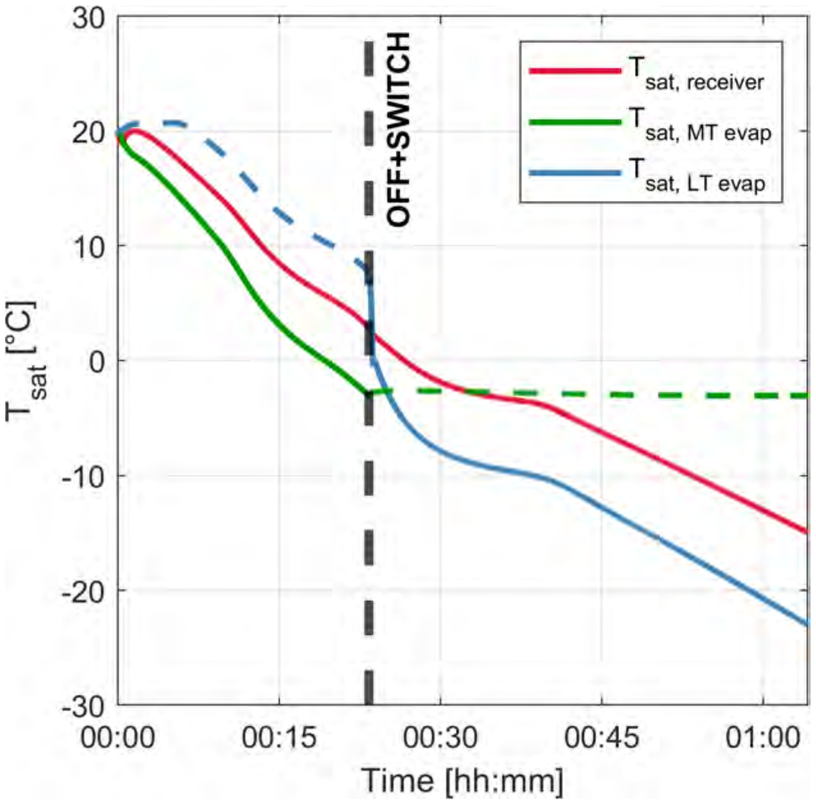
MT operation
(T_{amb} = 30 °C, $T_{set,MT}$ = 0 °C)

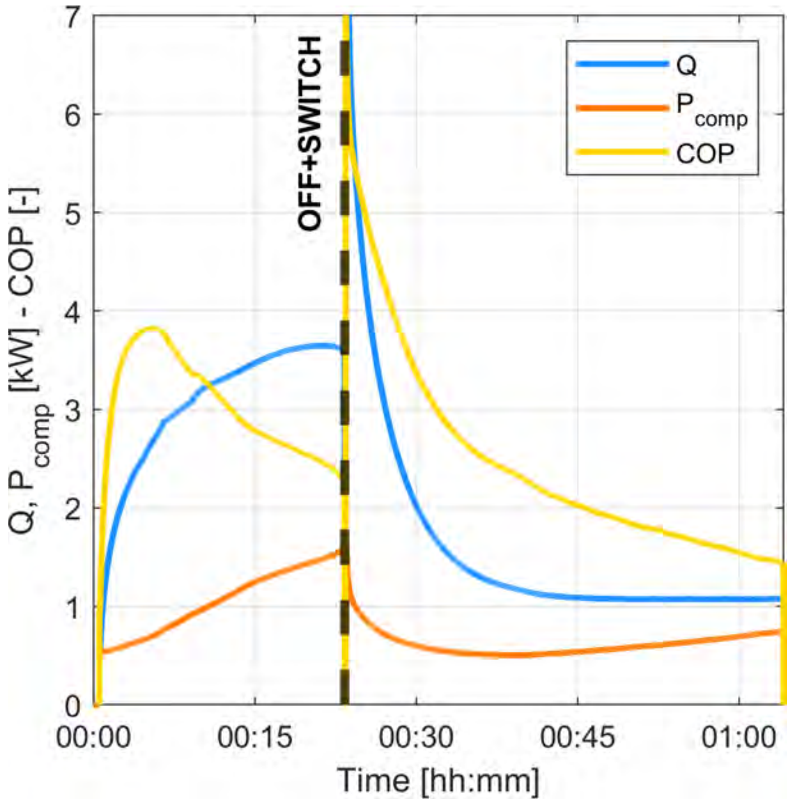


LT operation
(T_{amb} = 30 °C, $T_{set,MT}$ = -20 °C)

DYNAMIC NUMERICAL RESULTS

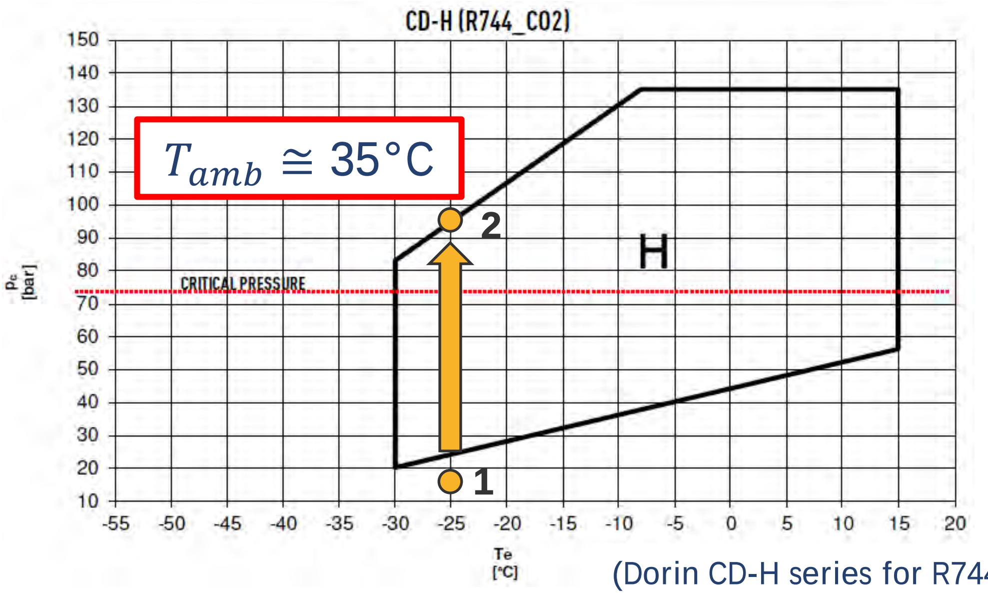
- Dynamic behavior numerically evaluated:
  - Pull-down from thermal equilibrium with environment (T_{amb} = 30°C) to MT temperature set point ($T_{set,MT}$ = 0°C) in MT ejector cycle;
  - The unit is then switched to LT ejector cycle and the pull-down to LT temperature setpoint ($T_{set,LT}$ = -20°C) is performed.





MULTI-TEMPERATURE SYSTEM CHALLENGES

- Single compressor envelope



(Dorin CD-H series for R744)

- Control complexity
  (switch between LT / MT / LT+MT and dynamic response)

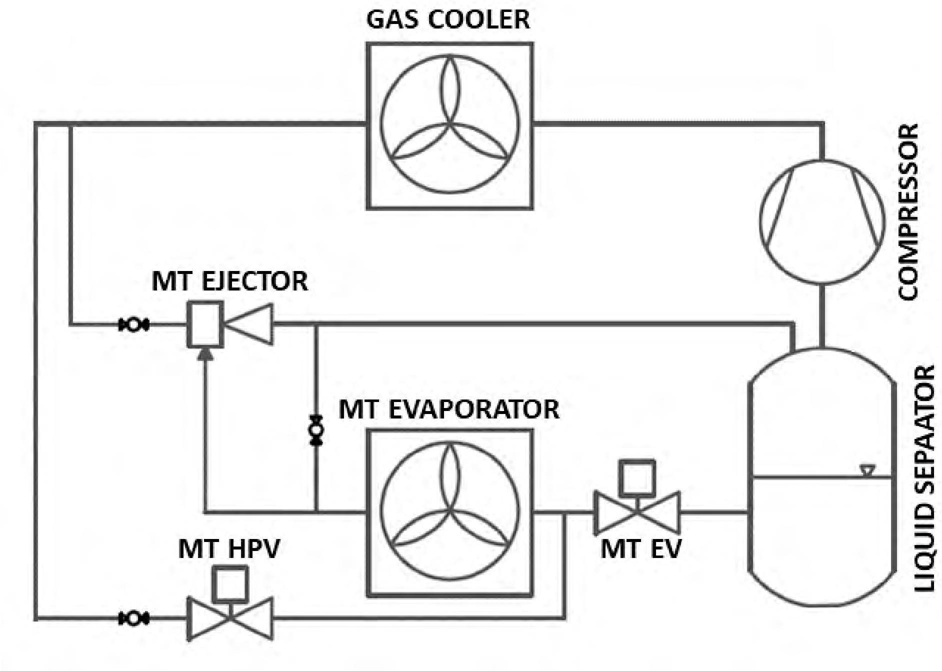
- Compressor mass and dimensions

Dimensions:
L 50 cm, d 28 cm

Weight:
73 kg

MT UNIT FOR FIRST DEMONSTRATOR PROTOTYPE

- MT cycle only with back-pressure and ejector configurations
- Optimization of weight and engumbrance for components (i.e. scroll variable-speed compressor istead of semihermetic compressor)



Dimensions:
H 30 cm, d 15 cm

Weight:
13.8 kg

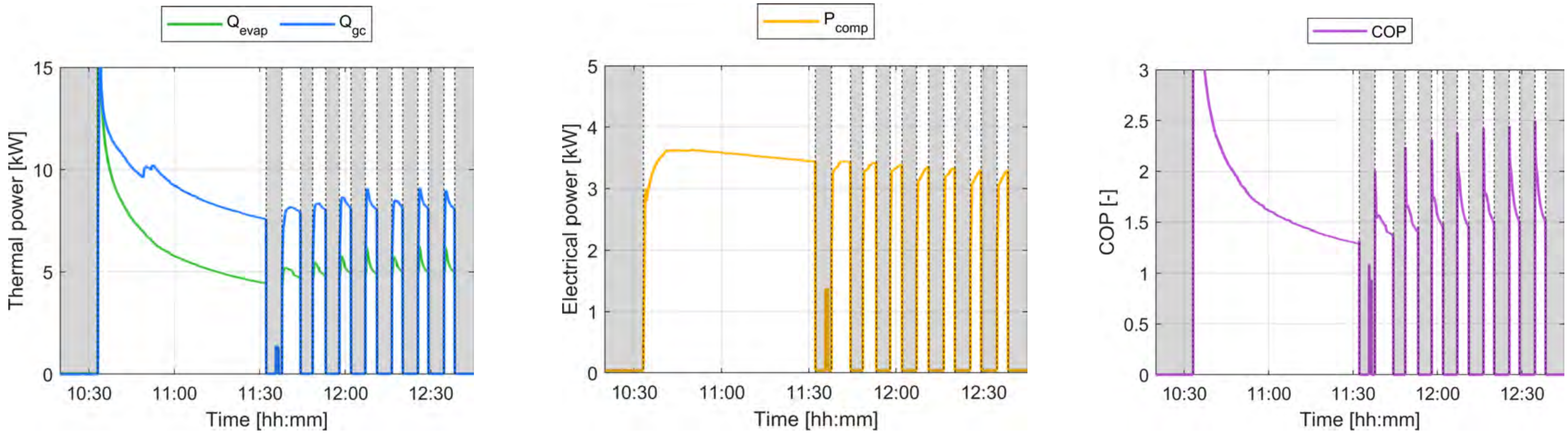
- Design, components choice and final prototype construction now in progress together with ENEX S.r.l.

MT UNIT EXPERIMENTAL TEST RIG

- Prototype stationary unit of the MT CO_2 unit installed in ITC-CNR laboratories.
- Final steps of installation and setup of the experimetal unit.

MT UNIT EXPERIMENTAL RESULTS

- First tests in back-pressure configuration were performed to verify the correct system operation;
- Mass flow meters and power meters not yet installed: refrigerant mass flow rate and compressor power draw were estimated according to operating parameters (e.g. pressure ratio) and components data sheets;
- Back-pressure configuration: example of pull-down from thermal equilibrium with the environment ($T_{amb} \approx 27$ °C) to the internal temperature set-point (-1 °C < T_i < 2 °C), with ON/OFF operation.



FUTURE WORK

- Experimental test campaign on stationary MT unit in the lab;
- Validation of numerical model against experimental data;
- Use of numerical model to finalize the structure and the components sizing for the smaller and optimized transport unit;
- Construction of final unit prototype;
- Installation of final prototype on a medium-sized electric van, equipped with solar panels on the top of the insulated box;
- Evaluation on the field of the performance of the refrigeration unit during real delivery missions of food products.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101036588

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EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

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EUROPEAN FOOD CHAIN SUPPLY
TO REDUCE GHG EMISSIONS BY 2050

07/12/2023

Demonstrators Webinar

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EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

Sustainable display cabinets with thermal energy storage

Denis Leducq

INRAE

Renewable energy and intermittency

Importance of energy storage solution

- European roadmap: share of renewable energy sources in EU at least 42.5% by 2030
- Renewable energy sources are intermittent by nature
  - Dependant of weather conditions
  - High fluctuations of energy power generation
  - Use of fossil fuel should be avoided to compensate the variability

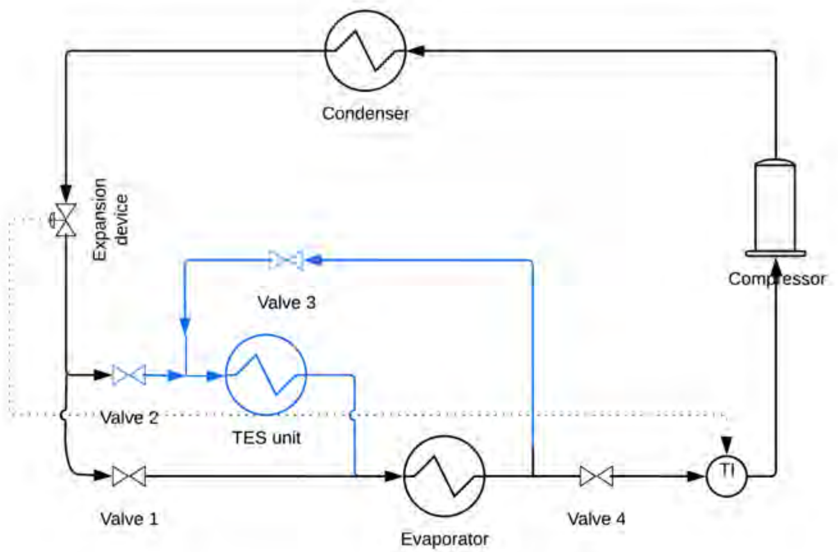
- A tool to manage the intermittency: Demand Side Response (**DSR**)
  - To balance production and consumption by reducing the demand

Refrigerating equipments with energy storage in the food supply chain have the potential to be used for Demand Side Response

Demonstrated technology

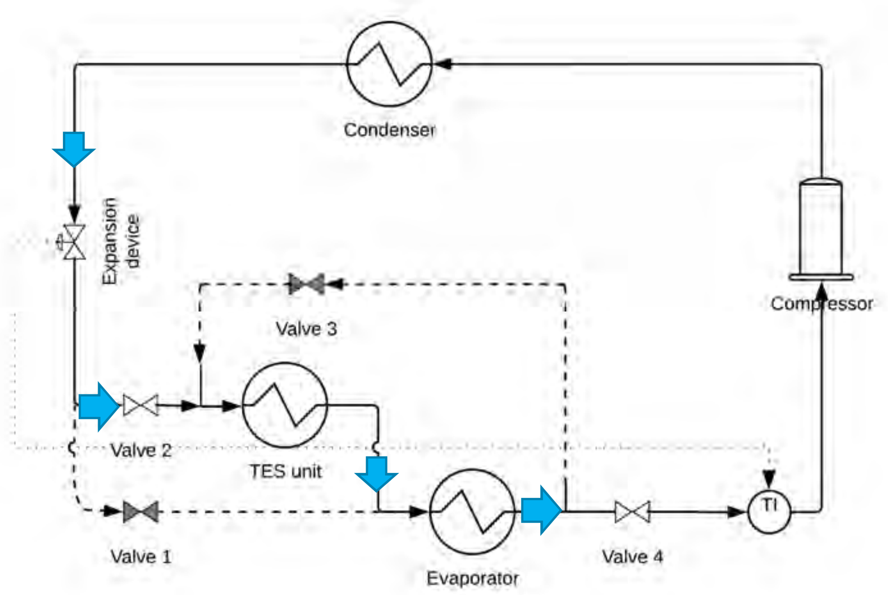
Thermal storage unit in a refrigerating equipment for DSR

- Storage unit integrated in a vapour compression cycle
  - Main advantage: better efficiency due to direct heat transfer between refrigerant and PCM
  - Natural circulation due to thermosiphon effect



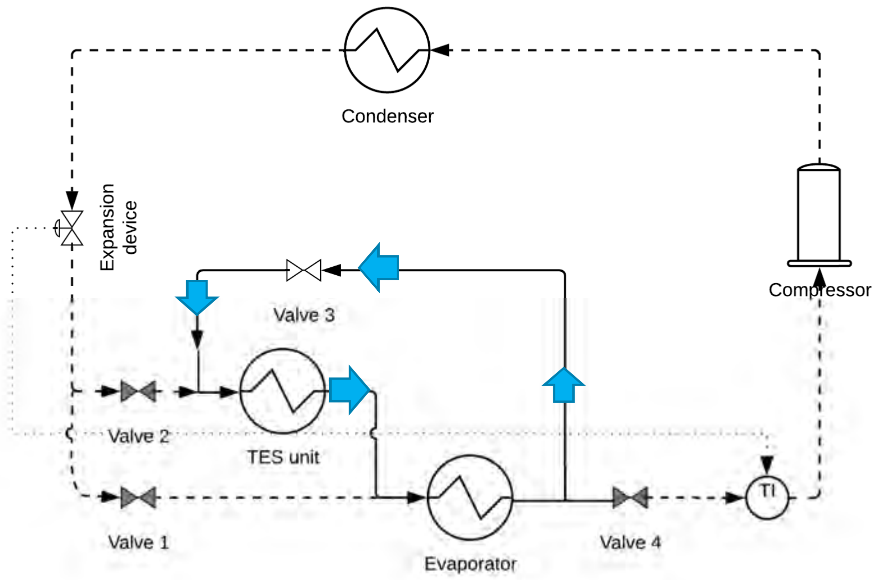
How does it work ?
Charging the accumulator

- Principle
  - Valve 1 closed and 2 opened
- Pre-evaporation in the accumulator
- Can be controlled
  - Charge / discharge activated only if required
  - When valve 2 closed and 1 opened : regular system



How does it work ?
Discharging

- Closed loop between the thermal storage unit and the evaporator
  - Valves 1,2,4 closed, valve 3 opened
  - Refrigerant flow without pump
    - Thermosiphon effect (driven by gravity)
  - Cooling provided by the accumulator instead of the refrigerating system
    - Refrigerant evaporates in the evaporator and condensates in the accumulator
- Technology not only for display cabinets
    - Refrigerators, cold rooms, milk tanks…

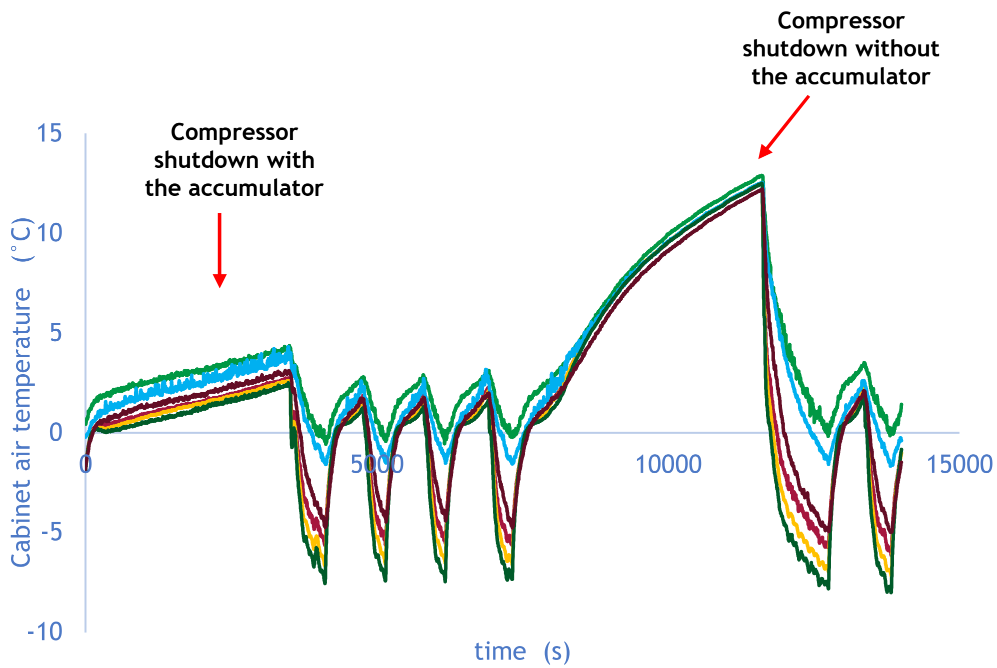


Demontrator in ENOUGH project
Laboratory prototype

- Material and method
  - Closed doors display cabinet
  - Instrumentation
  - PCM RT-4
    - Mixture of paraffin
    - Phase change/ -4°C to -7°C,
    - 15 kg
  - Thermal storage unit: 90cm x 9cm x 22,5cm
  - Controlled temperature room

Air temperatures when compressor is shut down (empty cabinet)

- Air temperatures in top, middle and bottom shelves
- With accumulator discharge
  - Slow increase, less than 4°C
- Without accumulator discharge
  - Quick increase reaching 13°C



10% product load, 22°C ambiant temperature

Testing charging / discharging scenarios (DSR) with a loaded cabinet

Air temperature with / without the thermal storage unit

Room temperature (°C)	Thermostat temperature (°C)	Mode	Product load (%)	Doors	Air temperature (°C)	Difference (°C)
19	-3	normal	50	Closed	1,38	+0,20
19	-3	with DSR	50	Closed	1,58	
19	-3	normal	90	Closed	0,53	+0,07
19	-3	with DSR	90	Closed	0,60	
17	-3	normal	90	Closed	0,67	+0,12
17	-3	with DSR	90	Closed	0,79	
22	-3	normal	90	Closed	0,46	+0,16
22	-3	with DSR	90	Closed	0,62	
17	-1	normal	90	Closed	2,16	+0,07
17	-1	with DSR	90	Closed	2,23	
19	-3	normal	90	Opening regime	0,79	+0,21
19	-3	with DSR	90	Opening regime	1,00	
17	-3	normal	90	Opening regime	0,89	+0,10
17	-3	with DSR	90	Opening regime	0,99	

Testing charge discharge scenarios

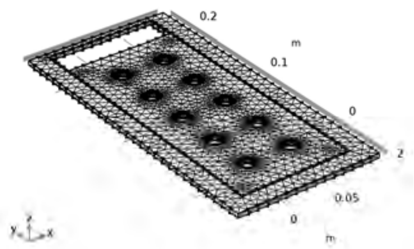
Energy consumption with / without the thermal storage unit

Room temperature (°C)	Thermostat temperature (°C)	Mode	Product loading (%)	Cabinet doors	Energy consumption over 24h (kWh)	(%)
19	-3	normal	50	Closed	8.14	- 10%
19	-3	with DSM	50	Closed	7.29	
19	-3	normal	90	Closed	8.65	- 4%
19	-3	with DSM	90	Closed	8.34	
17	-3	normal	90	Closed	7.36	- 2%
17	-3	with DSM	90	Closed	7.21	
22	-3	normal	90	Closed	9.04	+ 0.64%
22	-3	with DSM	90	Closed	9.10	
17	-1	normal	90	Closed	6.79	- 5%
17	-1	with DSM	90	Closed	6.42	
19	-3	normal	90	Opening regime	7.76	- 4%
19	-3	with DSM	90	Opening regime	7.45	
17	-3	normal	90	Opening regime	6.77	- 4%
17	-3	with DSM	90	Opening regime	6.47	

Next step: building a field test prototype

- Designing a second prototype with EPTA
- Remote display cabinet, CO_2 as refrigerant
- Accumulator with optimized geometry
  - 30% heat transfer increase
- Will be tested in a relevant environment

Epta



Conclusion

- Energy storage is a key technology to reach carbon neutrality
  - Potential of food refrigerating systems to play the role of thermal batteries
- Demand Side Response can be implemented in food retail using display cabinets with thermal energy storage units
- A novel technology of thermal storage is demonstrated in ENOUGH project in laboratory and in relevant environment
  - This technology can be applied to many other equipments in food supply chains

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101036588

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THANK YOU !

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