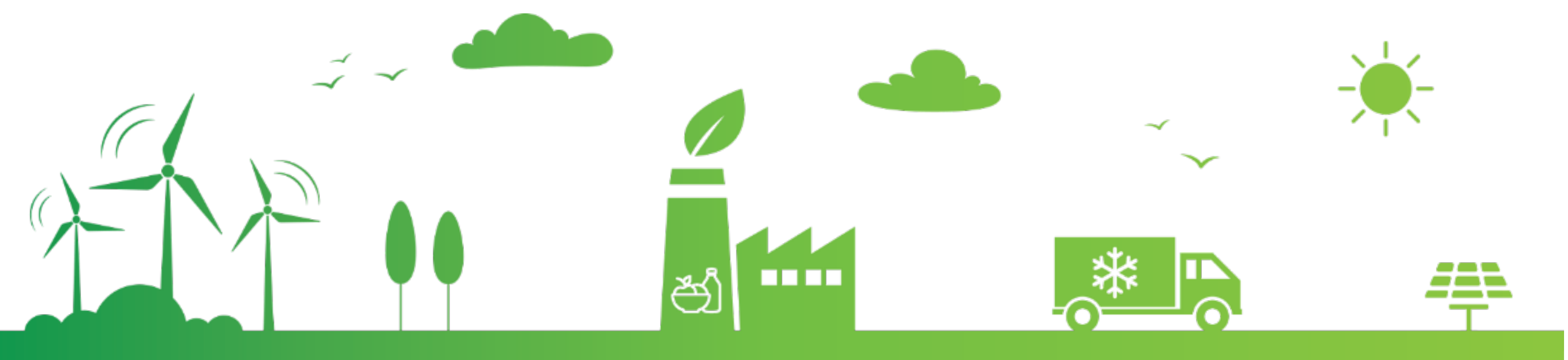
Economic and environmental inception report

Best practices in EE and RES solutions to value-chain level

By Ferretti I., Marchi B.,
Zanoni S., Zavanella L.

31st May 2024

This project has received funding from the European Union's Environment and Climate Action (LIFE 2014–2020) programme under grant agreement No 101119828



Project Information

Project Title	Renewable Energy and Energy Efficiency in the Value Chain
Project Acronym	LIFE22-CET-REEValue
Project Number	101119828
Project Dates	January 2023 – October 2026
Abstract	The REEValue project aims to generate value-chain collaborations among businesses in target NACE codes[1], through which energy efficiency (EE) and renewable energy (RES) opportunities will be identified and implemented. This will be done by gathering all the latest technical EE, RES, and value-chain collaboration model information, matching this to financial support mechanisms, translating this into easily understood formats for businesses which are transferable to other entities or projects, and carrying out a detailed study into the project's impact and the potential of value-chain collaborations for EE and RES. Technical information will be gathered from energy audit reports and by analysing the outputs and conclusions of relevant EU projects. This information will be translated into an easily understandable and widely transferrable format. Businesses will be able to use this resource to identify EE, RES opportunities and value-chain collaboration models. The project will also support businesses by matching them to financing measures for EE, RES and value-chain collaboration projects for each participating member state. Two online diagnostic and matching tools will be developed allowing this, designed to be portable to other EU project or entity websites. The project will offer Deep Dive: value-chain collaboration mentoring sessions to support businesses in developing value-chain collaborations. These 3-month programmes will be led by trained and experienced green mentors, with the participation of Sammontana representatives. The project will publish a report analysing project achievements, and providing an inventory of potential EE, RES and value-chain collaboration models for participating businesses, detailing energy savings potential, investment required, and barriers to overcome.

[1] See Annex 2: Relevant NACE codes

About

The REEValue project aims to generate value-chain collaborations among businesses in target NACE codes, through which energy efficiency (EE) and renewable energy (RES) opportunities will be identified and implemented.

The specific goals of REEValue are:

- EE projects implemented by participating businesses: 6000 businesses in 4 Member States (MS) targeted with an engagement rate of 10% and a subsequent implementation rate of 10% of engaged businesses. During the project lifespan a total cumulative Primary Savings of 3.53GWH is anticipated, increasing to a total cumulative value of 13.48 GWH over the next 5 years.
- RES projects implemented by participating businesses: 6000 businesses in 4 MS targeted with an engagement rate of 10% and a subsequent implementation rate of 10% of engaged businesses. During the project lifespan a total cumulative Primary Savings of 3.78 GWH is anticipated, increasing to a total cumulative value of 18.9 GWH over the next 5 years.
- EUR Millions of investments by participating businesses: a minimum of 30 businesses in 4 MS investing EUR 3,370,000.
- The consortium has also identified 3 companies who have agreed to earmark over 7 million euros for EE, RES & value chain collaboration investments over the next few years. The project will be working closely with them to provide guidance in identifying opportunities to maximise the benefits of their energy investments.

This will be done by gathering all the latest technical EE, RES, and value-chain collaboration model information, matching this to financial support mechanisms, translating this into easily understood formats for businesses which are transferable to other entities or projects, and carrying out a detailed study into the project's impact and the potential of value-chain collaborations for EE and RES. Technical information will be gathered from energy audit reports and by analysing the outputs and conclusions of relevant EU projects. This information will be translated into an easily understandable and widely transferrable format. Businesses will be able to use this resource to identify EE, RES opportunities and value-chain collaboration models. The project will also support businesses by matching them to financing measures for EE, RES and value-chain collaboration projects for each participating member state. Two online diagnostic and matching tools will be developed allowing this, designed to be portable to other EU project or entity websites. The project will offer Deep Dive: value-chain collaboration mentoring sessions to support businesses in developing value-chain collaborations. These 3-month programmes will be led by trained and experienced green mentors, with the participation of Sammontana representatives. Sammontana is a large EU company with a highly successful value-chain collaboration model through which EE and RES are integrated into equipment provided to its clients. The project will publish a report analysing project achievements, and providing an inventory of potential EE, RES and value-chain collaboration models for participating businesses, detailing energy savings potential, investment required, and barriers to overcome.

Legal notice

This project has received funding from the European Union's Environment and Climate Action (LIFE 2014–2020) programme under grant agreement No 101119828.

Table of contents

Foreword

The focus of the present report is on:

- the definition of the boundaries of the value chains of the different products (belonging by the NACE sector of the project) with details on the energy consumption characterizing the different stages involved in the production and supply of the goods;
- the investigation of the main best practices among the energy efficiency (EE) measures and renewable energy solutions (RES) for the improvement of the energy performance of the value chain;

an analysis of the barriers to exploiting these untapped opportunities and policy recommendations on how to overcome them.

Value chain

“A value chain refers to the full life cycle of a product or process, including material sourcing, production, consumption and disposal/recycling processes” [WBCSD (2011) Collaboration, innovation, transformation: Ideas and inspiration to accelerate sustainable growth - A value chain approach, p.3 & 5].

“The idea of the value chain is based on the process view of organisations, the idea of seeing a manufacturing (or service) organisation as a system, made up of subsystems each with inputs, transformation processes and outputs. Inputs, transformation processes, and outputs involve the acquisition and consumption of resources - money, labour, materials, equipment, buildings, land, administration and management. How value chain activities are carried out determines costs and affects profits.” [Porter, Michael E., "Competitive Advantage". 1985, pp 11-15. The Free Press, New York].

“There’s a temptation to use “value chain” and “supply chain” interchangeably, but there is a difference in the concepts that is significant. The supply chain model – which came first – focuses on activities that get raw materials and subassemblies into a manufacturing operation smoothly and economically. The value-chain notion has a different focus and a larger scope. A supply chain is simply a transfer of a commodity from one stakeholder to another in a chained manner. The value chain is the value addition at different stages of transfer. In different stages of value chain, different stakeholders add value to the product to increase the end product value. In other words, a value-chain analysis looks at every step from raw materials to the eventual end-user – right down to disposing of the packaging after use. The goal is to deliver maximum value to the end user for the least possible total cost.” [Reddy Amarender A. (2013) Training Manual on Value Chain Analysis of Dryland Agricultural Commodities, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), p.4]

“The value chain concept has several dimensions. The first is its flow, also called its input-output structure. In this sense, a chain is a set of products and services linked together in a sequence of value-adding economic activities. A value chain has another, less visible structure. This is made up of the flow of knowledge and expertise necessary for the physical input-output structure to function. The flow of knowledge generally parallels the material flows, but its intensity may differ.

The second dimension of a value chain has to do with its geographic spread. Some chains are truly global, with activities taking place in many countries on different continents. Others are more limited, involving only a few locations in different parts of the world.

The third dimension of the value chain is the control that different actors can exert over the activities making up the chain. The

actors in a chain directly control their own activities and are directly or indirectly controlled by other actors." [McCormick, D and Schmitz, H (2001) Manual for Value Chain Research on Homeworkers in the Garment Industry, Institute for Development Studies, p.17-19]

Value Chain Collaboration Categories

Value chain collaboration refers to the cooperation among different supply chain players to achieve common goals and improve overall performance.

There are some key aspects in value chain collaboration:

1. Communication: Clear, frequent, and balanced communication helps to build strong relationships within the supply chain and facilitates the exchange of information, ideas, and best practices.
2. Execution: It involves sharing resources, expertise, and responsibilities to achieve mutual benefits and improve overall supply chain performance.
3. Governance: for supporting supplier interaction and collaboration. It involves establishing protocols, guidelines, and frameworks for measuring and sharing value among supply chain partners.
4. Organizational Redesign: sometimes there is the need to make necessary changes within organizations to promote collaboration. It may involve restructuring departments, roles, and responsibilities to align with supply chain goals.
5. Benefit-Sharing: It ensures that the investment in collaboration pays dividends and the value created is shared equitably among partners.
6. Knowledge Transfer: Collaboration requires specific skill sets and knowledge. Knowledge transfer, as well as talent management and continuous learning are key factors to promote effective collaboration within the value chain.
7. Data Sharing and Integration: Sharing and integrating data across the value chain is crucial for effective collaboration. Modern supply chain collaboration software enables enterprises to connect different parts of the supply chain, specify requirements, and resolve potential disruptions more efficiently.
8. Shared Interests and Solutions: Successful collaboration requires parties to empathize with each other's interests and work together to find solutions that benefit all stakeholders.

Value chain collaboration models for energy savings involve the coordination and cooperation of different actors within the supply chain to improve industrial energy efficiency. The goal in to identify and implement energy-saving measures throughout the value chain, resulting in cost savings, reduced environmental impact, and increased competitiveness. There are four value chain collaboration model:

1. **Low Intensity Collaboration**: At the low intensity level, the focus is on harmonizing and sharing data with relevant entities. This involves establishing standardized data collection and reporting processes across the value chain. By sharing energy consumption, production, renewable and efficiency data, stakeholders can gain insights into their energy performance and identify areas for improvement.
2. **Moderate Intensity Collaboration**: it means not only harmonizing and sharing data but also allocating budget towards requested energy actions. In this model, value chain members actively participate in energy performance improvement initiatives by committing financial resources to implement identified energy-saving measures. By investing in energy actions, such as energy audits, equipment upgrades, or process optimization, value chain members can collectively achieve greater energy efficiency and cost savings.
3. **Advanced Intensity Collaboration**: This model emphasizes the importance of integrating energy considerations into product design and service offerings to drive overall energy performance. For example, a manufacturer may provide energy-efficient equipment to its clients, who are downstream value chain partners. By ensuring that the equipment supplied meets energy performance standards, the manufacturer contributes to energy efficiency improvements throughout the value chain.
4. **High Intensity Collaboration**: The highest level of value chain collaboration for energy performance improvement involves entering into collaborative agreements across the value chain. This model aims to coordinate actions focused on energy throughout the entire value chain. Value chain members proactively collaborate to identify opportunities for collective energy efficiency improvements, share best practices, and jointly invest in renewable energy projects or infrastructure. By aligning their efforts, value chain partners can maximize energy performance, optimize resource utilization, and achieve sustainable outcomes.

List of best practices

The goal of the present work is to identify best practices for improving value chains with regard to sustainability and energy aspects in the project NACE sectors. In particular these best practices are grouped in different categories such as: inventory management, transport system and policy, waste management, energy community, energy generation, industrial symbiosis, bill of materials, refrigeration system and building.

For each measure is indicated the category to which it belongs, the type of collaboration among different value chain players and the intensity of collaboration. Furthermore, the type of measure indicates if it belongs to energy efficiency (EE) or renewable energy (RES) solution.

Each best practice is reported in Table 1, and details on specific case studies have been reported in the technical sheets provided in the Annex 1.

Category	Description of Measure	Collaboration	Intensity of collaboration	Type of measure	Results	Main NEBS
Change the inventory policy	Use of the consignment stock - VMI inventory technique in order to reduce the (refrigerated) inventory and increase the service	Yes, the actors share information in order to optimize the inventory of the VC	Advanced	EE	Cost reduction ● Chilled prod.: -32% ● Frozen prod.: -49%	● Lower CO2 emissions ● Inventory optimization
Change the transport policy	Optimize the network in order to reduce the distance among the different logistics points.	Yes, the actors share information in order to optimize the transports	Advanced	EE	● Savings: +4%/year ● CO2 Emissions: +3%/year	
Change the transport policy	Optimised travel routes (e.g., reduction of empty return trips), modal shift	Yes, the actors share information in order to optimize the transports	Advanced	EE	Reducing fuel consumption	● Time and cost saving ● Reducing vehicle aging ● Reducing pollutants ● Energy management
Change the transport system	Improved insulation of trucks (e.g., air curtain)	Yes, the actors share information in order to optimize the transports	Advanced	EE	● Pay Back time air curtain: 8 months ● Energy savings: ○ Insulation: up to 30% ○ Air curtain: up to 40%	● Food quality ● Less maintenance
Change the transport system	Use insulated transport unit in order to reduce the energy consumption for refrigerated/heated transport	Yes, the actors share information in order to optimise transports and storage	Advanced	EE	● Investment: 3,800 €/PRU ● Pay Back time: < 1 year	● Food quality ● Lower fuel consumption ● Lower refrigerant leakages ● Negligible maintenance ● Handling & Storage
Waste management	Actors decide to change the packaging and/or withdraw the packaging	Yes, the packaging is defined in the VC specification and influences the waste management	Advanced	EE	Less energy consumption (packaging manufacturing)	● Less Global warming potential ● Lower dependence on fossil fuels
Energy community	Define a community for the sharing of energy produced by RES in the community itself	Yes, the actors share information in order to optimize the sharing of energy	High	RES	Energy saving: 40% for building with the highest energy demand	● Reduced greenhouse gases emissions

Category	Description of Measure	Collaboration	Intensity of collaboration	Type of measure	Results	Main NEBS
						● Lower dependence on energy derived from fossil fuels
Industrial symbiosis	By-product exchanges and waste heat recovery	Yes, the actors share information to optimize production	High	EE	Savings: 0.68–1.6 M€/year	● Reduced greenhouse gases emissions ● Improved productivity ● Lower dependence on fossil fuels
Bill of material	Change the bill of material (ingredients) in order to reduce the specific energy consumption	Yes, the leader defines the BOM of the products optimizing the energy consumption of the VC	Low	EE	Less fossil fuel consumption (transport)	● Less Global warming potential ● Less land use change
Refrigeration System	Alternative refrigeration technologies: e.g., solar cooling systems, thermal chillers, heat pumps	No	/	RES		● Energy substitution ● Decarbonised energy used
Refrigeration System	Retrofit of R22 refrigeration system by centralized ammonia (NH_3) system	No	/	EE	● Investment: 300 k€ ● Savings: ○ 55 k€/year ○ 350,000 kWh/year	● Reducing greenhouse gas emissions ● Increased equipment life ● Product quality improvement
Refrigeration System	Optimisation of the cooling distribution system	No	/	EE	A well-balanced circuit can save up to 35% of energy consumption	● Reduced heat losses and pressure drops ● Less maintenance ● Prevent pipes degradation and pumps overconsumption
Refrigeration System	Adjustment of cooling temperatures	No	/	EE	3-5 % of less energy consumption per °C	Reduced effort due to temperature management system
Building	Refrigerated warehouse energy optimization (separated compartments)	No	/	EE	Less energy consumption	● Saving costs ● Green image
Energy generation	Energy storage systems	No	/	RES		● Reduced carbon emission ● Increased host capacity of RES ● Increased self-consumption ● Improved reliability

Table 1: List of best practices

Annex 1 – Best Practices

Consignment Stock adoption

Abstract

Cold supply chains are environmentally controlled logistics chains whose purpose is to preserve the quality of perishable goods from farm to fork.

The time-temperature relationship between chilled and frozen foodstuffs highly impacts the quality assured to customers [1].

Energy performance and quality losses also affect and are affected by inventory-production management policies.

A comparison among three policies, Lot-for-Lot, Traditional and Consignment Stock (CS) about energy consumption and environmental impacts shows that the CS agreement could be specifically relevant for food cold chains. CS consist in smaller lot and higher number of shipments. For chilled products, delivering in small but frequent shipments make more sense because they have a short display life and must be consumed almost immediately. As for frozen products, with CS most of the inventory is moved closer to the customer, thus reducing overall storage time.

Category

Change the inventory policy

Level of collaboration

Advanced

Results

- Total cost reduction:
  - Chilled product: -32%
  - Frozen product: -49%

Main NEBs

- Lower CO_2 emissions
- Inventory optimization

Description

Cold supply chains handle perishable goods preserving their quality by storing and transporting them at low temperatures. So they use refrigerated warehouses and trucks that consume large amounts of energy, thus emitting significant CO_2 amounts.

Food waste is mainly due to not suitable temperature control during one or different cold supply chain stages. Furthermore, even when temperatures are properly managed, quality loss, and consequently food waste, increases the longer it stays in warehouse and the more stages a chain has.

Inventory and production management policies have an important role in cold supply chain performance in terms of energy consumption and quality degradation.

Larger lots lead to more energy consumption due to longer storage time and higher filling levels at warehouses, meaning lower specific energy consumption (SEC) [2]. So, coordinating order quantities and their sizes has become fundamental. Joint economic lot-sizing (JELS) model helps to solve this kind of supply chains' problems. A JELS policy is either traditional [3] or follows a consignment stock (CS) agreement [4]. In the traditional or backward inventory stocking policy, the vendor produces and accumulates inventory up to a level and ships lots of equal sizes at equal intervals to the buyer, who pays the vendor upon receiving a shipment. The CS agreement is a forward inventory stocking policy where the vendor moves its inventory to the buyer's warehouse that only pays for the sold items. This policy could, in particular, be relevant for food cold chains, especially when the demand is stock-dependent [5].

Analysis of results

The results show lower costs for the CS, and the difference in costs between the two policy increases as the lot size grows.

Although CS shows to be more profitable than the traditional agreement (-32% of the total cost for the chilled meat and -49% for the frozen green peas), it is not always the same for all supply chains' players. In this case, a profit-sharing mechanism can resolve this discrepancy by making a CS agreement work for the vendor and the buyer [6]. The difference in total costs between the traditional and CS policies are lower for chilled meat since the quality degradation is faster than for frozen peas.

Energy costs and loss in value due to quality degradation should be considered since they highly impact on the optimal decision variables and on the convenience of the different coordination policies, especially when more than one shipment is considered. For chilled products, losses in value due to degradation in quality amount to about 4% of the overall cost for chilled meat if the Consignment stock coordination policy is adopted.

Frozen green peas consume more energy (higher costs) but subzero temperature significantly slows degradation in quality and subsequently reduces its associated costs. This is done by either lowering the temperature or shortening the storage time.

Larger lots result in longer storage times and subsequently more quality losses, especially for chilled products. The traditional policy has slightly lower value losses due to quality degradation than the CS one with increases in Q. However, the lower degradation doesn't make the traditional agreement more suitable coordination mechanism than the CS due to other costs which are much higher, especially the energy ones. The temperature impacts the trade-off of energy and quality costs and, consequently, the optimal lot size. Higher temperatures increase the relevance of the quality losses. So, reducing the lot size shortens the storage time and, subsequently, product deterioration.

The results also do not recommend a lot-for-lot coordination policy but a consignment stock agreement for both products, which consist in smaller lot and higher number of shipments. The rationale is that chilled products have a short display life and must be consumed almost immediately, whereas delivering in small but frequent shipments make more sense. As for frozen products, the results recommended a consignment stock policy where most of the inventory is moved closer to the customer, thus reducing the time a product spends in stock at the vendor and the buyer.

Opportunities and barriers

Opportunities	Barriers
Supply chain inventory level optimization	Agreement between partners
Low energy consumption	Increasing of transports
Low CO_2 emissions	

Calculation model

A comparison between Consignment Stock policies has been made by developing a calculation model that considers a constant demand for the final product with quality depending on the temperature and time spent in the warehouse for two types of products: a commodity product (e.g., chilled meat) and a seasonal one (e.g., frozen green peas). Production and consumption rates are quite similar for the first product, while the second has a production rate much higher than its demand rate to satisfy annual demand. For both products, the vendor processes the raw material to produce the finished products in the package required by the buyer, which directly satisfies the consumers' demand. Previous processing stages on the raw materials are not relevant from a quality-energy trade-off point of view since no refrigeration is needed.

References

[1] Ndraha, N., Hsiao, H., Vlajic, J., Yang, M., Lin, H.V., 2018. Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations. Food Control 89, 12–21. doi:10.1016/j.foodcont.2018.01.027

[2] Marchi, B., Zanoni, S., Jaber, M.Y., 2020. Energy Implications of Lot Sizing Decisions in Refrigerated Warehouses. Energies 13, 1739. doi:10.3390/en13071739

[3] Hill, R.M., 1997. The single-vendor single-buyer integrated production-inventory model with a generalised policy. Eur. J. Oper. Res. 97, 493–499. doi:10.1016/S0377-2217(96)00267-6

[4] Braglia, M., Zavanella, L., 2003. Modelling an industrial strategy for inventory management in supply chains: The "Consignment Stock" case. Int. J. Prod. Res. 41, 3793–3808. doi:10.1080/00207540802275863

[5] Zanoni, S., Jaber, M.Y., 2015. A two-level supply chain with consignment stock agreement and stock-dependent demand. Int. J. Prod. Res. 53, 3561–3572.

[6] Marchi, B., Zanoni, S., Ferretti, I., Zavanella, L.E., 2018. Stimulating investments in energy efficiency through supply chain integration. Energies 11. doi:10.3390/en11040858

Configuration of cold supply chain distribution network

Category
Change the transport policy

Level of collaboration
Advanced

Results
Increasing n° of DCs from 2 to 6:

- Savings (year): +4%
- CO_2 Emissions (year): +3%

Abstract
The right configuration of cold supply chain distribution network could have a significant impact on overall value chain eco-efficiency performance in terms of costs and CO_2 emissions. The number of Distribution Centers (DCs) and their localization are the two factors that most influence the network configuration results. In general, when the number of Distribution Centers (DCs) increases, the supply chain cost decrease, while an increase in the environmental impact of the chain is reached [4].
Results obtained do not determine an 'optimal' solution, but they suggest which economic and environmental performance can be reached for different values of DCs involved in the supply chain.

Description

About 15% of worldwide energy is used in cold chains and cooling systems [1] and since 40% of food transports require refrigeration [2], the growth of global food demand will highly increase the energy request and related CO_2 emissions [3].
In order to set an eco-efficient cold value chain, many issues influencing economic as well as environmental results should be treated. The most important is network configuration, i.e. number and location of involved participants, flows between actors, and any other element for the specific case that can contribute to the eco-efficiency results of the chain.
The distribution network object of the case study concerns in:

- procuring and harvesting fresh green peas by a group of farmers (F)
- deep-freezing them at the treatment plant (TP)
- distributing them to a given number of retailers (R), involving in the distribution network a certain number of DCs.

Considering many scenarios, involving 2 to 6 DCs, the goal of the study is to estimate the trade-off between economic and environmental impacts of the refrigerated food supply chain. Each configuration considers different temperature levels for the goods leaving the TP.

Analysis of results

The more the number of DCs increases, the more total emissions increases while total cost decreases. Considering 6 instead of 2 DCs in the network can lead to a saving of about 1.8 million $/year but an increasing in CO_2 emissions of 2.2 million tons/year.
Eco-efficiency results are usually calculated as combinations of cost and CO_2 equivalent emissions. Results are used as a supporting tool for managerial decision, since they offer the values for configurations, but it is a manager's responsibility to choose whether to opt for a solution that minimizes costs or environmental impacts or to implement an intermediate-result strategy.
Each cost component and environmental emission related to supply chain has been taken in account and grouped into five categories: transport, process, holding, opening (TP and DCs), and quality degradation.
Quality degradation represents the main cost and emissions component followed by process cost and emissions. The main degradation of quality occurs to fresh storage before the deep-freezing treatment of goods. While process costs and emissions are mainly due to the energy required for deep-freezing treatment as

well as to setup for production batch change.

A further analysis concerns the impact on costs and emissions for different number of DCs of two other parameters, the storage temperature at TP after deep-freezing treatment and the lot size for shipment from a DC to a single retailer. For values of Tfrozen 253K and 263K total cost decreases for increasing numbers of DCs, while for Tfrozen = 273K total cost increases: this is achieved because of quality, higher the temperature means higher quality degradation. Emissions are not conditioned by such a different temperature value. Costs depend on lot size while emissions are independent.

Opportunities and barriers

Opportunities	Barriers
Lower energy consumption	Investments for new DCs
Cost savings	Trade off with CO_2 emission

Calculation model

To calculate the eco-efficiency result for each network configuration, it has been designed an economic model that considers main costs related to processing, transporting, storing refrigerated vegetables and opening DCs are considered, while the environmental performance has been evaluated using GEMIS 4.5 software and database to define emission factor coefficients of different elements (energy, fuel, trucks, building and plant installation).

The model is only applicable for frozen food distribution networks.

Following is a list of parameters related to costs and environmental performance involved for each specific process stage (Table [1]).

Stage	Costs	Environmental performance
Harvesting and delivery to TP	Transport costs from the F to the TP	Fuel consumption for the transport of goods from F to TP
	Quality depletion during the transport from the F to the TP	Truck production
Storage of fresh foods at TP	Opening a treatment plant (building and plant installation);	Building and plant installation at TP
	Inventory holding costs of fresh goods (including energy required)	Energy required for fresh goods storage
	Quality depletion of fresh products during storage at TP	
Deep freezing processing at TP	energy required for the deep-freezing process;	Energy required by the deep-freezing process activities
	Setup costs involved in the same process	
	Quality depletion of fresh products during deep-freezing process	
Storage of frozen products at TP	Inventory holding costs of frozen goods (including energy required)	Energy required for frozen goods storage
	Quality depletion of frozen products during storage at TP	
Delivery from TP to DCs	Transport costs from TP to the i-th DC	Fuel consumption for transport of goods from F to TP
	Quality depletion of frozen goods during the transport from TP to the i-th DC	Truck production
Storage of frozen product at DCs	Opening a certain number of DCs (building and plant installation)	Building and plant installation at DCs
	Inventory holding costs of frozen goods (including energy required)	Energy required for frozen goods storage
	Quality depletion of frozen products during storage at DCs	

Delivery of frozen products from DCs to Rs	Transport costs to deliver all goods from DCs to all Rs	Fuel consumption for transport of goods from DCs to all Rs
	Quality depletion of frozen goods during transport from all DCs to all Rs	Truck production
Storage of frozen products at Rs	Inventory holding costs of frozen goods (including energy required)	Energy required for frozen goods storage
	Quality depletion of frozen products during storage at Rs	

Table [1]: List of model parameters for each stage of value chain

References

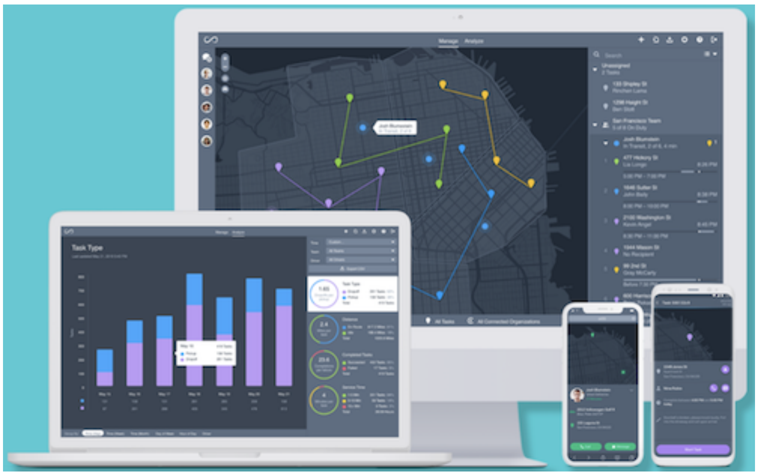
[1] Coulomb, D. 2008. "Refrigeration and Cold Chain Serving the Global Food Industry and Creating a Better Future: Two Key IIR Challenges for Improved Health and Environment." Trends Food Science Technology 19 (8): 413–417. doi:10.1016/j.tifs.2008.03.006.

[2] James, S. J., C. James, and J. A. Evans. 2006. "Modelling of Food Transportation Systems – A Review." International Journal of Refrigeration 29: 947–957. doi:10.1016/j.ijrefrig.2006.03.017.

[3] Vanek, F., and Y. Sun. 2008. "Transportation versus Perishability in Life Cycle Energy Consumption: A Case Study of the Temperature- Controlled Food Product Supply Chain." Transportation Research Part D 13: 383–391. doi:10.1016/j.trd.2008.07.001.

[4] Zanoni,S., Mazzoldi, L & Ferretti, I. 2018. "Eco-efficient cold chain networks design", International Journal of Sustainable Engineering, DOI: 10.1080/19397038.2018.1538268

Optimized Travel Routes



Abstract

For improving the energy efficiency of a logistics company, it has been implemented a navigation system specifically developed for refrigerated transport.

Compared to conventional navigation systems, it considers in travel routes calculation not only the time and costs of the transport, but also the energy and costs due to the cooling system. This concerns, for example, the duration of the route related to the cooling load. Furthermore, it also considers detours possibility to increase the volume saturation, automatically the system reports when it is energetically and economically convenient or not.

The routes can be optimized in such a way that, on the one hand, minimizing the energy that has to be provided by the vehicle and the cooling system and, on the other, maximizing the vehicle saturation. Accordingly, one performance indicator (KPI) of the Energy Management System (EMS) is the energy consumption per kilogram of goods.

Category

Change the transport policy

Level of collaboration

Advanced

Results

- Reducing fuel consumption

Main NEBs

- Time and cost saving
- Reducing vehicle aging
- Reducing pollutants
- Energy management

Description

The cold chain logistics distribution industry not only demands all goods can be timely distribution but also requires to reduce the entire logistics transportation cost as far as possible. The adoption of specific software for transport optimization helps to make best decisions regarding transport plans and to save costs and time by assigning shipments to available vehicles in an optimal way. These solutions are usually a dedicated module of ERP systems or standalone applications integrated with them.

Furthermore, distribution vehicle route optimization is the key problem of cold chain logistics transportation cost calculation. In addition to the usual data of a navigation system route options (time, distance and fuel consumption), the cooling system usage is also a crucial factor that has to be taken in account.

The total energy consumption resulting from different route options is calculated through a navigation system developed specifically for refrigerated transports.

The energy consumption results from time to destination, the cooling load, from the route distance and the fuel consumption for driving. On the other hand, the volume load of the transporter must be maximized, which sometimes requires deviations by the route for picking up other goods. Knowing if detours are reasonable from an energy point of view can be easily calculated by the system. Truck drivers can access the data using an app and thus react to route changes even at short notice.

The app suggests the most energy-efficient, the fastest and the most cost-effective route. The navigation system considers also toll and travel expenses costs due to personnel costs etc.

A KPI is calculated for each route, it is not set in relation to the route because some detours contribute to energy efficiency maximizing load or minimizing travel time. The kilometers driven must therefore be considered separately.

Improvement details

The main advantage of this efficiency measure is that it saves fuel considering the cooling load when choosing the route. For example, toll roads that appear to be an uneconomical route option using a conventional navigation system may indeed be financially feasible considering costs of cooling over the duration of the journey.

Benefits

The main advantages of this navigation program are the energy and cost savings that can be achieved compared to conventional navigation.

In addition, this program is directly linked to EMS so the results can be monitored to promote the continuous improvement process, and to identify further efficiency measures.

Opportunities and barriers

Opportunities	Barriers
Lower fuel consumption and related cost	Cost of software
Negligible maintenance	Cost for new vehicle
Worldwide availability	Training required
Easy utilization	
Improved food quality	

References

[1] Habibur Rahman M., Fashiar Rahman M., Tseng T.-L., Estimation of fuel consumption and selection of the most carbon-efficient route for cold-chain logistics (2023)
[2] Amorim P., Almada-Lobo B., The impact of food perishability issues in the vehicle routing problem (2014)

Improved insulation of trucks

Abstract

A logistics company that mainly transports chilled and frozen food wants to save both energy and costs by reducing the cooling load of its trucks. In order to achieve this, it was analyzed how heat enters the cold store and thus increases the cooling load. In this way, possible inefficiencies are to be identified and assessed to what extent this can be avoided.

The study has shown that especially transmission and open doors lead to heat transfer into the truck interior. Especially in the case of frozen goods, the loss due to the exchange of air when the doors are opened is very high.

For this reason, two energy efficiency measures were implemented that were able to significantly reduce the cooling load. Firstly, the vans were additionally insulated or old insulation, whose heat transfer coefficient has deteriorated over time, was replaced. Secondly, air curtains were fitted to the doors, which can significantly reduce energy losses via air circulation when the doors are opened.

Category

Change the transport system

Level of collaboration

Advanced

Results

- Pay Back time air curtain: 8 months
- Energy savings:
  - Insulation: up to 30%
  - Air curtain: up to 40%

Main NEBs

- Food quality
- Less maintenance

Description

Door openings and transmission are the main cause of refrigerated truck heating (see Figure 1). To minimize these problems the insulation of trucks is improved and air curtains are installed.

The old insulation is cleaned and checked for any damage. The age of the insulation and trucks are considered, because it leads an efficiency loss. If necessary, trucks or the insulation will be renewed. For example, vacuum insulation can result in energy savings of up to 30% [1].

As a second measure, air curtains are used, which can result in energy savings of up to 40% [1]. In addition, open doors are avoided if possible.

Improvement details

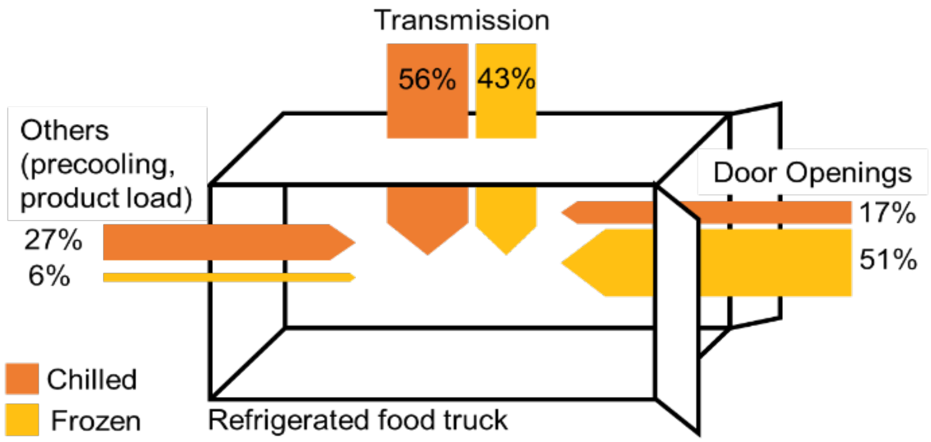
The mission is to reduce heat transfer to the cooled area. Improved insulation reduces thermal conduction and air curtain minimizes convection by air circulation. In this way, the cooling load is reduced and thus the fuel consumption for refrigeration.

Benefits

The main benefit of insulation and air curtain is the decrease in energy consumption and costs for cooling system (fuel and CO_2 emission).

One more benefit of the air curtain is the less exposure to temperature fluctuations of transported goods. For example, it has been reported that avocados change less color due to an air curtain. [2]

Compared to an automatically closing door, the air curtain does not cause any time delays and truck drivers are very satisfied with the solution. By energetical point of view, it has been observed that the air curtain has the same effect as an automatically closing door. [2]



Opportunities and barriers

Opportunities	Barriers
Lower fuel consumption and related cost	Costs for air curtain
Negligible maintenance	Training required
Worldwide availability	
Easy utilization	
Improved food quality	

References

[1] Tassou, S. 2010. 'Energy Savings in Refrigerated Trucks' presentation. School of Engineering and Design, Brunel University. https://grimsby.ac.uk/documents/defra/08Jun10_Transport.pdf. Accessed 19 March 2020.

[2] Brightec BV. http://brightec.nl/. Accessed 19 March 2020.

Portable Refrigerated Unit

Abstract

Refrigerated transport has an high impact in energy consumption and CO_2 emission for maintaining the required temperature to preserve perishable goods.

Portable refrigerated unit (PRU) is a new solution that can be used by cold chain (logistic) operators when the volume saturation of a standard refrigerated vehicle is low (e.g., Less than Truck Load transport) without the need of specific investment in special truck or infrastructures. Indeed, PRUs can be stored in non-refrigerated traditional warehouses by connecting them to the power supply, furthermore, ensuring the cold chain is maintained they favor a better products preservation.

Thanks to lower weight, higher insulation and lower power consumption, the PRU is more eco-efficient than traditional refrigerated transport vehicles using vapor compression system.

Category

Change the transport system

Level of collaboration

Advanced

Results

- Investment: 3,800 €/PRU
- Pay Back time: < 1 year

Main NEBs

- Food quality
- Lower fuel consumption
- Lower refrigerant leakages
- Negligible maintenance
- Handling & Storage

Description

The demand of food distribution across global cold supply chains is continuously growing, this means an increase of the energy request and the associated carbon emissions related to refrigeration transport.
Keeping the temperature of perishable goods in the desired range during the transportation activities is expensive but mandatory to preserve the quality of foods.
The increasing quantity of home deliveries, and the higher quality expectations of customers, bring to an increased use of refrigeration in order to reach lower temperatures, which result in high amount of energy consumption [1].
The majority of refrigerated road transportation is conducted with semitrailer insulated rigid boxes. The most popular insulation is expanded polyurethane foam with cyclopentane as the blowing agent and the most common refrigerating system is the vapor compression system, which performance and power requirements are usually tested at full load. Such condition is far from reality, as reported by Defra (2008) report, average payload for refrigerated goods for the UK (2007 and 2008 data) varies between 16% of medium rigid vehicles, to about 30% of articulated vehicles (32 and 38 tons). To maintain temperature with these Less than Truck Load (LTL) conditions refrigeration system may be switched on and off or, in some cases, its capacity can be modulated: such modifications lead to a consequent efficiency reduction.
There are other factors affecting performances of transportation units, such as exterior weather conditions, expected interior conditions, infiltration of air and pollutions and physical deterioration. Furthermore, logistic activities, such as temporary doors openings for loading and unloading, cause air infiltrations which lead to a remarkable increase of the cooling demand and consequently of the energy requested [2]. For instance, a food product can be subject to about 50 door-openings during a multi-drop delivery [3]. There are also ground operations that causes increasing of temperature due to the period of time that goods are stored at inappropriate ambient temperatures waiting for handling.
Euroengel S.r.l., an Italian company, designed and produced a Portable Refrigerated Unit (PRU) named ColdTainer with the aim of overcoming the previously defined issues [4].

PRU Details

PRU are made of polyethylene for food use with a rotational molding technology, without internal junctions and with all corners rounded for an easy cleaning in compliance with Directive 93/43/EEC

(HACCP). The structure also allows to obtain unique impact resistant cable bodies. The thermal insulation is made of expanded polyurethane, with thickness ranging from 65 to 130 mm. Furthermore, the larger models are tested in accordance with ATP regulations and have a technical dispersion coefficient "K" less than 0.40 Wm2/K.

The refrigeration units use Danfoss hermetic compressors (12-24Vdc), developed specifically for use on vehicles and therefore with low absorption and can function perfectly even in the presence of vibrations and angles up to 30°C. Coolant gas is R134a, non-flammable and compatible with environmental regulations, for + 4 °C solutions while R404a for – 20 °C solutions.

Portable Unit for hot food transporting

The same issues mentioned above also apply to the transport of hot foods.

Food preparation, cooking operations and their subsequent distribution and consumption can be performed at different times and places. In consequence, a more or less long transfer of hot foods can be expected, in physical and temporal term. This process must be able to guarantee that the food temperature, from cooking to consumption, is always maintained above +65° C, thus avoiding risks of bacterial growth.

Current solutions for transport in hot conditions include the use of passive isothermal containers with limited autonomy in terms of temperature maintenance. It is standard practice to bring the cooked food's temperature to levels higher than necessary in order to extend the holding time to the minimum required by the standards of + 65° C. This however affects the quality and taste of food.

New active isothermal containers, in particular the versions with built-in battery, are able to solve these critical issues: they allow maintaining a constant food temperature for long periods, without traumatic changes of temperature; they guarantee the integrity of the nutritional values, and the consistency and the colors of the foods; they avoid the risk of passing through the critical area of bacterial growth, optimizing time and energy.

Benefits

The use of active refrigerated containers allows the respect of cold chain also for transport of limited quantities of perishable stuff. PRU contributes on reduction of delivery time, costs CO_2 emissions, and also in the risk of food contamination. This entails environmental benefits in terms of reducing energy consumption and CO_2 emissions. The economic and environmental benefits derived from modularity of the transport

device that provides energy savings at different levels of volume moved. [4]
In particular, this technology simplifies transport and storage of refrigerated goods. PRUs can be stored in non-refrigerated traditional warehouses by connecting them to the power supply, this allows to avoid investments for implementing refrigerated warehouses. These containers can be loaded with a forklift on a standard truck (powered by 12V/24V batteries of the vehicle) for direct delivery to final destination, avoiding the need for specialized refrigerated vehicles.
PRUs allow delivery and storage of refrigerated and non-refrigerated goods with a single transport/warehouse, since they allow to set different temperatures to each unit preventing the deterioration of goods. In particular, they allow to avoid the partitioning of the warehouse into smaller cells for the preservation of goods with similar characteristics.

Opportunities and barriers

Opportunities	Barriers
Lower fuel consumption	Cost for renovating fleet equipment
Lower CO_2 emission	
Lower refrigerant leakages	
High food quality preservation	
Little maintenance required	
Modularity of transport	
Handling & storage simplified	

Calculation model

Economic and environmental performance (i.e., CO_2 emissions), combined in eco-efficiency results of traditional refrigerated transport vehicles considering LTL case, are compared with those of a PRU solution considering the following quantities:

- energy consumption, generated from vehicle engine, necessary for refrigeration system (traditional solutions – long-distance and multi-drop) or for PRU and ventilation system (PRU solution)
- refrigerant consumption
- fuel consumption, for motive function of vehicle.

Data for refrigerated goods transport are taken from Defra (2008) report, with specific reference to Section 3 of the document (energy consumption of refrigerated road transport): in particular, fuel consumption, distances, refrigeration capacity and average payloads.

Both CO_2 emissions and costs are evaluated, first separately, then by varying the number of SKU (or PRU) delivered in a single shipment.

Also for high saturation values, when the number of SKU is limited (i.e., 8 units, representing the 100% saturation of cargo volume in case of PRU usage, but 50% considering multi-drop and 44% for long-distance solutions), the PRU presents the best eco-efficiency result.

The choice of considering no more than 8 SKU, is related to the main assumptions of low saturation of vehicles for refrigerated transport.

Economic and environmental benefits derived from modularity of the transport device that provides energy savings at different levels of volume moved. The other types of transport refrigeration do not have this kind of modularity, which would allow them to be efficient even when the volumes and frequency involves the unsaturation of the adopted vehicles.

References

[1] S.A. Tassou, G. De-Lille, Y.T. Ge, Food transport refrigeration – Approaches to reduce energy consumption and environmental impacts of road transport, Appl. Therm. Eng. 29 (2009) 1467–1477. doi:10.1016/j.applthermaleng.2008.06.027.

[2] A. Carullo, S. Corbellini, M. Parvis, A. Vallan, A Wireless Sensor Network for Cold Chain Monitoring, IEEE Trans. Instrum. Meas. 58 (2009) 1405–1411. doi:10.1109/TIM.2008.2009186.

[3] S.J. James, C. James, J.A. Evans, Modelling of food transportation systems – a review, Int. J. Refrig. 29 (2006) 947–957. doi:10.1016/j.ijrefrig.2006.03.017.

[4] I. Ferretti, L. Mazzoldi, S. Zanoni, Environmental impacts of cold chain distribution operations: A novel portable refrigerated unit, Int. J. Logist. Syst. Manag. 31 (2018) 267–297. doi:10.1504/IJLSM.2018.094938.

[5] Defra (2008) Greenhouse Gas Impacts of Food Retailing: Final Report, DEFRA, UK.

[6] www.coldtrainer.it

Change the packaging

Abstract

Food packaging plays an essential role as it protects the food from external contaminants to increase the shelf life. The high usage of conventional food packaging derived from fossil fuel contributes to the environmental issue as it creates long-term wastes [1]. Packaging contributes to 42% of plastic waste [2]. The use of non-plastic packaging generated significantly less impact than the use of plastic materials, it is not only due to the origin of the material but also to the manufacturing process and the electricity consumption for their production.

For example, a Life Cycle Assessment (LCA) was performed for evaluating energy and environmental performance of the strawberry supply chain by modelling various stages from transport from growers to retail storage and considering different types of primary packaging: plastic (PET and RPET – recycled PET), cardboard, recycled paper and molded pulp.

Category

Bill of material/Waste disposal

Level of collaboration

Advanced

Results

- Less energy consumption (packaging manufacturing)

Main NEBs

- Less Global warming potential
- Lower dependence on fossil fuels

Description

Strawberry has a short shelf life and requires intensive use of energy for low-temperature storage and distribution [3]. The European Union [4] established three types of packaging for the strawberry industry. Primary packaging which are sale units for consumers (i.e., punnet of strawberries), secondary packaging which groups several units (i.e., crate) and tertiary packaging for handling and transport (i.e., pallet).

An analysis of energy and environmental performance of the strawberry supply chain has been made considering various types of primary packaging: plastic (PET and RPET – recycled PET), cardboard, recycled paper and molded pulp.

The supply chain segment considered in this analysis began with the transport from the grower to the packing station and ended with the retailer storage:

- T1: Transport from the grower to the packing station
- S1: Refrigerated storage at the packing station
- T2: Transport in a refrigerated truck to a distribution platform
- S2: Refrigerated storage and allotment at the distribution platform
- T3: Transport in a refrigerated truck to a retailer
- S3: Refrigerated storage in a cold room at retailer

The strawberries were harvested and put directly into punnets in greenhouses. Then, the punnets were sent to the packing station where they were packed (flow-pack) in the ambient air at 14°C. The primary packaging was an RPET punnet with a macro-perforated polypropylene film around the punnet. Secondary packaging (grouping 10 punnets) was a plastic crate, while a pallet was the tertiary packaging consisting of 48 crates.

The energy consumption related to the cooling and temperature maintenance of one strawberry punnet was evaluated for three cold storage stages (S1 packing station, S2 distribution platform, S3 retail cold room) using the method developed in [5] and data from the field study.

Details of Analysis

The considered functional unit for the study was 1 kg of strawberries at the end of the supply chain. The product loss was taken into account in this mass assuming that biowaste is treated by anaerobic digestion (50%) and composting (50%).

The packaging materials may affect the quality of the strawberry and hence the loss rate of the strawberry fruits due to the cushioning or other functional protection performance. In the case of strawberries, water loss from fruit and humidity from the ambient environment could be absorbed by packages made of molded pulp, paper and cardboard, while this is not the case for plastic packages. But this information was not considered because was not available. EcoInvent database [6] was the data source for manufacturing processes of various packaging, for environmental impacts of the energy generation system and also for transport data.

Opportunities and barriers

Opportunities	Barriers
Lower dependance on fossil fuel	Risk of loss of product quality
Lower energy consumption for packaging manufacturing	Increase in costs for packaging
Lower CO_2 emission	
Green image	

Calculation model and results

The environmental impacts were analyzed by Simapro software (v9.3) using the IMPACT 2002+ method [7].
The results show that the packing station stage S1 was more energy consuming than the other two stages S2 and S3 because S1 duration was longer and the product was subjected to the highest temperature drop (from 16°C to 6°C). The total electrical consumptions of the storage stages for one 250 g strawberry punnet were 3932 J (Text = 20°C) and 6764 J (Text = 40°C).

For each packaging type, a single score was obtained by summing up the score of four categories: human health, quality of ecosystems, climate change and resources. In this analysis, the use of molded pulp, cardboard and recycled paper, generated significantly less impact than PET and RPET and their scores were almost the same. The packaging material that brought the most significant impact is PET, mostly because of its petrochemical origin. The RPET, as a recycled material, had better environmental performance than PET. In the present analysis, the smallest single score was obtained for cardboard.
The LCA process was applied to the use of primary packaging with the most and least impact, PET and cardboard. In the case of PET, the process that had the most significant impact was the packaging production 47%, followed by the refrigerated transport T2 (39.4%). For cardboard, the process that had the most significant environmental impact is the refrigerated transport T2 (64.6%).
The results were similar for configurations using cardboard, molded pulp and recycled paper. Instead, also for RPET, the production of punnets played a significant role. Concerning on global warming, the general behaviors were quite similar: the plastic packaging (PET and RPET) generated more CO_2 than molded pulp, cardboard and recycled paper.
The packaging disposal is a complex issue since various treatments could be done for

each material and regulations are different among countries, so it was not considered in this study.

References

[1] Timotius Weslie et al 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1143 012037
[2] Geyer R, Jambeck J R, Law K L 2017 Sci. Adv. 3 (7) e1700782
[3] Kelly, K., Madden, R., Emond, J.P., do Nascimento Nunes, M.C., 2019. A novel approach to determine the impact level of each step along the supply chain on strawberry quality. Postharvest Biol. Technol. 147, 78–88.
[4] EU, 1994. European parliament and council directive 94/62/ec, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31994L0062
[5] Duret, S., Hamon, E., Hoang, H.M., Stahl, V., Derens-Bertheau, E., Delahaye, A., Laguerre, O., 2020. Modelling methodology of temperature and energy consumption in food plant: application to puff pastry. Int. J. Refriger. 115, 28–38.
[6] Ecoinvent, 2022. ecoinvent version 3, https://ecoinvent.org/th e-ecoinvent-database/data-releases/ecoinvent-3-8/#!/v3.
[7] EU, 2010. ILCD Handbook: analysing of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment.
[8] Anthony Delahaye et. Al., 2023. Strawberry supply chain: Energy and environmental assessment from a field study and comparison of different packaging materials. Int. J. Refriger. 153, 78–89.

Energy community

Abstract

By sharing energy produced from renewable sources, energy communities promote the reduction of energy consumption derived from the grid. An analysis of different energy sharing strategies with two distinct models for the Renewable Energy Communities (REC) operation (individual self-consumption with only sharing generation surplus and collective self-consumption) has been done by simulating a REC over a year, and implementing various sharing coefficients, both fixed and variable.

The benefits offered to each member depend on the considered model and on the individual energy needs. Fixed energy sharing coefficients tend to be more interesting to buildings with lower energy needs, while larger consumers take more advantage from the variable energy sharing coefficient. The benefits for buildings operating as a REC are evident when comparing to their individual operation without generation surplus sharing.

Category

Energy community

Level of collaboration

High

Results

Energy saving: 40% for building with the highest energy demand

Main NEBs

- Reduced greenhouse gases emissions
- Lower dependence on energy derived from fossil fuels

Description

The European Union (EU) has been encouraging its member states to increase the share of renewable energy sources (RES) into their energy pool. This encouragement aims to increase energy security and to decrease emission of greenhouse gases (GHG) into the atmosphere when energy is generated using fossil fuels, and [1]. By the consumer side, the energy generated from local renewable sources is used to reduce energy import from the grid and the respective costs [2]. To enhance the local usage of RES and associated benefits related to self-consumption, the concepts of Renewable Energy Community (REC) have been introduced and encouraged by the EU. These entities are entitled to share locally generated energy among their members at a lower cost, when compared to the price of energy imported from distribution grids.

Self-consumption of RES refers to the immediate usage of energy generated from renewable sources to satisfy energy demand. This practice can be conducted at both individual and aggregated levels and the literature shows that the second option presents better results when compared to an individual operation due to the sharing of generation surplus among community members and the respective reduction of energy import from distribution grids [3].

Another strategy that can be adopted by local entities to reduce the cost of purchasing energy is to create energy purchasing centers in order to aggregate the energy demand of each member and move along the discount curves offered by the different providers.

Details

To assess the impacts of the association of buildings (or companies) as a REC, real data regarding the buildings' electricity consumption were collected. The buildings selected for the case study have different electricity consumption profiles due to the following factors: size, usage type, and year of construction.

<u>Building 1</u>

A multipurpose pavilion, used for concerts, sports tournaments, and other events. It has a demand peak during the night.

<u>Building 2</u>

The City Hall building, its demand peak occurs around noon.

<u>Building 3</u>

A public market, the demand peak occurs early in the morning

<u>Building 4</u>

A public school, despite the holiday period (July-September) its demand peak occurs around noon.

PV systems are used to generate electricity on-site in each building. The number of modules for each building, used to calculate the PV system output power, results from a survey with the total installed power and annual generation considering the meteorological data. PV modules are assumed to be installed to maximize annual generation, and achieve a specific production of approximately 1,350 kWh/kWp.

The installation of storage devices is not considered, surplus electricity is entirely exported to the low voltage distribution grid. The sharing process is made by applying energy sharing coefficients, which are related to the percentage of the locally generated energy that is due to each member.

Four different scenarios are compared:

1. baseline operation, representing the current individual energy consumption of the buildings (no PV systems installed);
2. individual operation with PV systems installed at each building;
3. REC operation with buildings able to perform individual self-consumption and sharing only the surplus of the locally generated energy
4. REC operation with buildings performing collective self-consumption of the total electricity generated by the considered PV systems.

Three types of energy sharing coefficients in scenarios 3 and 4 are considered.

1. A 25% fixed and equal coefficient (FEC), so all members receive the same amount of energy surplus.
2. A fixed and proportional coefficient (FPC). In this case, the amount of energy surplus received by each member is proportional to its relative annual energy consumption (comparing to the annual consumption of the four buildings).
3. The last one refers to a variable sharing coefficient (VSC), defined at each 15-min time-step, according to the relative energy consumption of each member.

In the 2nd scenario there is a natural decreasing on the imported energy and associated costs, due to the energy generated by the PV systems, which is partially used to fulfil the building user's needs. The referred mismatch results in the total export of 34% of all electricity generated by the local sources.

In the 3rd scenario the configuration implies that buildings prioritize individual self-consumption of local generation, being the eventual surplus shared among the members that, on a given time-step, were not able to fulfil their electricity needs with the respective PV systems. The amount of energy self-consumed in this scenario is the same as in scenario 2, due to the individual self-consumption occurring prior to the sharing process.

The main characteristic of the 4th scenario is that the PV systems are not used for individual self-consumption before the sharing process takes place, resulting in more energy to be shared among REC members.

Results

The collected results show that the operation as a REC (Scenarios 3 and 4) conducts to lower energy costs and less imported energy, when compared to their individual operation (Scenario 2). Scenario 1, where no PV systems are available, is the one with the worst performance in terms of costs and imported energy. Regarding the energy sharing coefficients, selecting the best option depends on the considered scenario and demand profile of each building. However, it is observed that the VSC leads to a better REC performance, from a collective point of view, with lower energy costs and less energy imported. Nevertheless, when individual self-consumption is allowed for the REC members (Scenario 3), there is a lower advantage from choosing the VSC, due to the individual benefit already achieved by the individual self-consumption and less energy needs when the sharing process happens.

Opportunities and barriers

Opportunities	Barriers
Lower dependence on main energy grid with energy cost reduction	Cost of investment for RES and local grid
Reduced greenhouse gas emissions	Geographical proximity
Lower dependence on fossil fuels	

References

[1] European Commission, The European green deal, Eur. Community 53 (2019) 24, https://doi.org/10.1017/CBO9781107415324.004.

[2] H. Queiroz, R. Amaral Lopes, J. Martins, Automated energy storage and curtailment system to mitigate distribution transformer aging due to high renewable energy penetration, Elec. Power Syst. Res. 182 (2020), 106199, https://doi.org/10.1016/j.epsr.2020.106199.

[3] R.A. Lopes, J. Martins, D. Aelenei, C.P. Lima, A cooperative net zero energy community to improve load matching, Renew. Energy 93 (2016) 1–13, https://doi.org/10.1016/j.renene.2016.02.044.

[4] H. Queiroz, et al., Assessment of energy sharing coefficients under the new Portuguese renewable energy communities regulation, Heliyon 9 (2023) e20599.

By-products exchanges and waste heat recovery

Category
Industrial symbiosis

Level of collaboration
High

Results
Savings: 0.68-1.6 M€/year

Main NEBs

- Reduced greenhouse gases emissions
- Improved productivity
- Lower dependence on fossil fuels

Abstract

By-products exchanges and waste heat recovery among co-located companies support the environmental impact reduction and energy and cost saving by the recovery of resources deriving as waste from production processes.

These kinds of network can improve the overall sustainability of the related companies from both economic and environmental points of view.

Resource recovery represents a key pillar in the transition from a linear to a circular economy eco-end for implementing industrial ecology.

Description

By-products exchanges are business-to-business relationships among near located companies where surplus resources generated from an industrial process, instead of being lost because generally considered as waste, are conveyed as raw materials in other processes. Direct inter-firm resource recovery is the cornerstone of the industrial symbiosis (IS) which principles include undertaking economic and environmental advantages for involved companies that are implementing the by-product exchange in order to profit by potentials offered by proximity [1,2].
These kinds of synergies can be adopted in food and beverage industry [3]: e.g., utilization of industrial food waste as a reagent in creating valuable compounds, energy recovery form waste food (biomethane production) or heat recovery from nearby industries processes.

Details

The case study speaks about the potential industrial symbiosis between a forging industry and a greenhouse installation near located [8]. The forging process is proper for the application of carbon capture and utilization (CCU) through horticulture enrichment, and the greenhouse proximity allows an easy pipelines transportation of CO_2. Furthermore, the waste heat of forging process could be used for heating of the greenhouse.
Just considering the use of CO_2 enrichment as CCU method for the reduction of industrial emissions, it is simple to understand economic and environmental impacts compared to a scenario with CO_2 enrichment is provided by heaters burning natural gas. The results show three economic savings: (1) the increase of revenues deriving from the CO_2 enrichment process, (2) avoiding of natural gas consumptions, (3) reduction of CO_2 emissions fees of the industrial plant.
Assuming 2 production cycles per year, the implementation of the industrial symbiosis network would ensure economic benefits between 0.68 and 1.6 M€/year.
While the CO_2 exchange would allow to reuse from 1,500 to 2,000 tons of CO_2 per cycle, which represent from 16 % to 21 % of the overall emissions of the considered industrial installation.

Benefits

IS promotes a collective approach for improving efficiency and resources utilization and, at the same time, to gain competitive advantage with both private and public benefits concerning environmental, economic and social performances [2,4,5]. These common benefits are bigger if compared to the sum of benefits that single companies could gain [6]. Furthermore, if we consider a collaboration between private companies and public authorities, IS ensures greater benefits also for public organizations [7]: (1) improved performance of the public service facilities; (2) cost efficiency for providing heat, cooling and electricity to public service facilities and (3) reduced environmental impact.

Opportunities and barriers

Opportunities	Barriers
Reduced greenhouse gas emissions	Cost of investment
Improved productivity	Geographical proximity
Lower dependence on fossil fuels	R&D issues
Economic savings	

References

[5] M.R. Chertow, "Uncovering" Industrial Symbiosis, J. Ind. Ecol. 11 (2007) 20. doi:10.1162/jiec.2007.1110.

[6] M.R. Chertow, Industrial symbiosis: Literature and Taxonomy, Annu. Rev. Energy Environ. 25 (2000) 313–337. doi:doi:10.1146/annurev.energy.25.1.313.

[7] I.A. Udugama, L.A.H. Petersen, F.C. Falco, H. Junicke, A. Mitic, X.F. Alsina, S.S. Mansouri, K. V. Gernaey, Resource recovery from waste streams in a water-energy-food nexus perspective: Toward more sustainable food processing, Food Bioprod. Process. 119 (2020) 133–147. doi:10.1016/j.fbp.2019.10.014.

[8] M. Martin, N. Svensson, M. Eklund, Who gets the benefits? An approach for assessing the environmental performance of industrial symbiosis, J. Clean. Prod. 98 (2015) 263–271. doi:10.1016/j.jclepro.2013.06.024.

[9] J. Zhu, M. Ruth, The development of regional collaboration for resource efficiency: A network perspective on industrial symbiosis, Comput. Environ. Urban Syst. 44 (2014) 37–46. doi:10.1016/j.compenvurbsys.2013.11.001.

[10] L. Cutaia, R. Morabito, Ruolo della Simbiosi industriale per la green economy, Energia, Ambient. Innov. - Spec. Green Econ. (2012) 44–49.

[11] B. Marchi, S. Zanoni, L.E. Zavanella, Symbiosis between industrial systems, utilities and public service facilities for boosting energy and resource efficiency, Energy Procedia. 128 (2017) 544–550. doi:10.1016/j.egypro.2017.09.006.

[12] B. Marchi, S. Zanoni, M. Pasetti, Industrial symbiosis for greener horticulture practices: the CO2 enrichment from energy intensive industrial processes, Procedia CIRP. 69 (2018) 562–567. doi:10.1016/j.procir.2017.11.117.

Bill Of Material changing

Category

Bill of material

Level of collaboration

Low

Results

- Less fossil fuel consumption (transport)

Main NEBs

- Less Global warming potential
- Less land use change

Abstract

Changing a product Bill Of Materials (BOM) could represent a solution to both increase environmental sustainability and reduce costs of entire food value chain. For example, replacing a raw material with one that comes from closer has a strong impact on transports and therefore it lead to reduction of fuel consumption and related emissions. For example, a Life Cycle Assessment (LCA) for ice-cream value chain in a UK company shows that the manufacturing of premium version of ice-cream flavors (chocolate and vanilla) has more environmental impacts than the regular flavors because of different recipes. Regular chocolate requires less cocoa powder, as well as regular vanilla is made with vanillin produced locally instead of vanilla extract made from beans thus leading to a transport reduction and a shortening of the supply chain.

Description

Ice cream is one of the most popular food worldwide and the sector is still growing. Vanilla and chocolate ice cream are the leading flavors in UK (36% of the total market share) [1].

At the same time, ice cream industry is one of the most energy-intensive in the food processing because of cold/frozen chain and cooling systems.

A Life Cycle Assessment (LCA) methodology is used to evaluate the environmental sustainability of UK ice cream supply chain about two versions of abovementioned flavors: vanilla regular, vanilla premium, chocolate regular and chocolate premium.

Ice cream ingredients include milk, cream, sugar, vanilla extract (premium vanilla ice cream), vanillin (the regular version), cocoa powder (chocolate flavor), eggs (premium products) and water. The premium variety has a higher content of milk fat and sugar and it also contains eggs and the premium chocolate variety has also more cocoa powder than its regular equivalent.

The main life cycle stages considered are: production of ingredients, ice cream manufacturing and packaging, distribution to and storage at the retailer (including transport), consumption at home and end-of-life waste management.

Environmental sustainability of each stage is evaluated by the following 18 impact categories: global warming potential, primary energy demand, ozone depletion,

fossil fuel depletion, ozone depletion, freshwater eutrophication, marine eutrophication, human toxicity, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, terrestrial acidification, agricultural land occupation, urban land occupation, natural land transformation, photochemical oxidant formation, mineral depletion, volumetric water consumption and water footprint.

Ice-cream LCA Details

Ingredients

Raw milk, vanillin and 40% of sugar are produced in the UK, the rest of sugar is imported from Brazil and refined in the UK [2]. Vanilla beans are cultivated in Madagascar and processed into vanilla extract in UK. Cocoa beans are cultivated in Ghana and processed to cocoa powder in the UK [3]. Egg yolk (pasteurized) is used for vanilla ice cream.

Manufacturing

Raw milk processing involves clarification and storage, homogenization and pasteurization, followed by separation into milk cream and skimmed milk. The latter is concentrated in an evaporator and then mixed with the rest of the ingredients, followed by their pasteurization. The mix is then cooled to room temperature and poured into plastic boxes while being simultaneously frozen. The ice-cream is then hardened, packed into secondary packaging and stored in a deep freezer [4].

Retail and consumption

It is assumed that the ice cream is distributed from manufacturer directly to retailer, where it is stored in a freezer for one week before being purchased by the consumer. Ice cream remains in the household freezer for one month on average [5]. Therefore, the electricity consumption is based on that duration and the volume of the freezer occupied.

Transport

The consumption of refrigerants and additional fuel usage must be accounted for, these data have been sourced from Tassou et al. (2009) [6]. Transport distances for the raw materials are based on the origin of the ingredients. The distance travelled by the consumer to purchase the ice cream has been calculated according to Pretty et al. (2005) [7].

Potential improvements

The main focus in terms of reducing the overall environmental impacts should be the raw materials stage, especially for raw milk production and cocoa cultivation. The impacts of milk could be reduced by modifications of animal feed [8] and by composting the manure [9].

The impacts could also be mitigated by reducing the amount of cream (and therefore the milk) or the percentage of cocoa in the recipe, especially in premium versions. But that could affect the quality of the products and most manufacturers would not consider that option. However, new manufacturers are starting to produce low fat and sugar products.

In the manufacturing stage, less energy-intensive processes should be considered, in combination with energy optimization and a switch to low-carbon energy sources.

If the energy reduction can be combined with a decrease in the storage time from 30 to 15 days, then the primary energy demand would be reduced by 12%, fossil fuel depletion by 11% and freshwater eutrophication by 14%.

Opportunities and barriers

Opportunities	Barriers
Lower fuel consumption	Loss of product quality/market
Lower CO_2 emission	R&D for new products

Calculation model and results

The environmental impacts have been estimated using the ReCiPe midpoint method [10] as implemented in GaBi V6.4 [11].

The results of the assessment shows that chocolate regular ice cream is the best option for nine impacts, although only marginally better than vanilla regular, premium alternatives have more environmental impacts especially chocolate because of cocoa cultivation.

Other important aspects are evidenced by sensitivity analysis about packaging and storage time.

Primary packaging: utilization of High-density polyethylene (HDPE) instead of Polypropylene (PP) affects only four impact categories, reducing them by less than 10%. PP ice cream tub contributing 22% and 19% of total fossil fuel depletion and primary energy demand, respectively.

Storage time: The energy consumed for deep freezing is the main contributor to the impacts from ice cream manufacturing. Two more storage times are analyzed, only six impacts are affected by this change. Doubling the storage period to 60 days increases the impacts of ice cream by 6%-13% while reducing it to 15 days, decreases them by up to 5%. Refrigeration at the retailer is the major cause of ozone depletion, contributing to 90% to the total impact. It also accounts for 10% of the total primary energy demand, fossil fuel depletion, global warming potential and freshwater eutrophication. For the extended storage of 14 days, ozone depletion increases by 95%, primarily due to refrigerant leakage. Moreover, freshwater eutrophication increases by 22% and mineral depletion by 19%, also due to the leakage. On the contrary, if the storage time is reduced to 3 days, ozone depletion is reduced by more than half (54%) and freshwater eutrophication and mineral depletion by 12%.

References

[9] Key Note, 2015. Ice Creams & Frozen Desserts. Rechmond Upon Thames: Key Note

[10] DEFRA, 2006a. Environmental Impacts of Food Production and Consumption (London: s.n).

[11] Audsley, A., et al., 2009. How Long Can We Go? an Assessment of Greenhouse Gas Emissions from the UK Food System and the Scope to Reduce Them by 2050. RCRN-WWF-UK, Cranfield, UK.

[12] Marshall, R.T., Goff, H.T., Hartel, R.W., 2003. Ice Cream, sixth ed. Kluwer Academic, New York.

[13] Foster, C., et al., 2006. Environmental Impacts of Food Production and Consumption. DEFRA, London.

[14] Tassou, S.A., De-Lille, G., Ge, T.Y., 2009. Food transport refrigeration e approaches to reduce energy consumption and environmental impacts of road transport. Appl. Therm. Eng. 29, 1467-1477.

[15] Pretty, J., Ball, A., Lang, T., Morison, J., 2005. Farm costs and food miles: an assessment of the full cost of the UK weekly food basket. Food Pol. 30, 1-16

[16] Roibas, L., et al., 2016. An analysis on how switching to a more balanced and naturally improved milk would affect consumer health and the environment. Sci. Total Environ. 566-567, 685-697.

[17] Hogaas, M.E., 2002. Life Cycle Assessment (LCA) of Industrial Milk Production. Chalmers University of Technology, Chalmers.

[18] Goedkoop, M., et al., 2013. ReCiPe 2008: a Life Cycle Impact Assessment MethodvWhich Comprises Harmonised Category Indicators at the Midpoint and thevEndpoint Level. Dutch Ministry of Housing, Spatial Planning and Environment,vAmsterdam.

[19] Thinkstep AG, 2016. Gabi V6.115 Version Software and Database [Online] Available at: http://www.thinkstep.com.

[20] Konstantas, A., Stamford, L., Azapagic, A., 2019. Environmental impacts of ice cream. Journal of Cleaner Production, 209, pp. 259–272

Alternative refrigeration technologies (solar cooling)

Category
Change refrigeration system

Level of collaboration
None

Main NEBs
- Energy substitution
- Decarbonised energy used

Abstract
Conventional refrigeration systems have an high environmental impact due to fossil fuel combustion and related CO_2 emissions. Innovative technologies have been developed to overcome these environmental issues, one of the most promising for replacing or reducing the usage of traditional refrigeration systems is the solar cooling. It is ready to be compared to conventional cooling equipment but climatic conditions have an high influence on its efficiency.
Solar cooling can be mainly obtained by various two technologies: (i) photovoltaic driven vapour compression chillers and (ii) heat driven cooling machines fed by solar collectors.

Description

Depending on the energy used, it is possible to define two types of solar refrigeration systems: solar thermal and solar electric cooling systems.
Solar electric cooling systems use electrical energy provided by photovoltaic panels (PV) to drive a conventional electric vapor compressor air-conditioning system saving up to 95% in electricity.
In solar thermal cooling systems, solar collectors convert solar energy into thermal energy and use it to drive thermal cooling systems through absorption, adsorption, and desiccant cycles.

Electricity-driven solar refrigeration systems

As mentioned above, solar electrical cooling systems are composed of two subsystems: photovoltaic panel and electrical refrigeration device. Photovoltaic cells transform light into electric power that is used by vapor compression systems, thermoelectrical system, or Stirling cycle.
The case study shows the implementation of this solution in a 995 m^2 supermarket located in Switzerland. Thanks to the roof installation of solar panels the supermarket consumes only the 40% of daily energy produced putting the rest into Swiss electrical grid. While during nights and winter time it draws electricity from the grid. Analyzing the annual results the supermarket produces more energy than it consumed becoming a ”positive” energy company since 2015.

Solar thermal cooling systems

Solar thermal cooling systems use solar heat to produce refrigeration effect. A solar collector gives heat to thermal compressor in a heat-driven cooling machine. The operating temperature is a fundamental parameter for the efficiency of a solar collector. At a higher temperature, the collector is less efficient delivering less heat to the compressor, while it is more efficient working with high temperatures. These opposite characteristics are taken into account during thermal solar system design.
Solar thermal cooling systems technologies:

- Thermo-mechanical: a heat engine converts solar heat to mechanical work that is transferred to compressor of a vapour compression refrigeration machine. This system is likely more expensive than a solar electric refrigeration system.
- Sorption refrigeration: uses physical or chemical attraction between a pair of substances to produce cooling power directly from thermal energy. The substance with lower boiling temperature is called

sorbate (refrigerant) and the other is called sorbent. The sorption systems can be subdivided into different technologies bases on different physical principles: absorption systems and physical or chemical adsorption systems.

- Desiccant cooling (or open sorption cooling): in a liquid desiccant cooling system, the liquid desiccant circulates between an absorber and a regenerator in the same way as in an absorption system. Water is typically used as the refrigerant and a desiccant as the sorbent for direct treatment of air in ventilation system. Desiccant dehumidification offers a more efficient humidity control than the other technologies.

Conclusions

There are many options to obtain refrigeration trough solar energy, however the average cost of these systems are higher than conventional cooling machines. But they are very interesting by environmental point of view because of decarbonization of energy produced for refrigeration.
Being technologies depending on climatic conditions, it is important to take into account having an alternative cold production system before choosing a solar refrigeration technology.

Opportunities and barriers

Opportunities	Barriers
Energy substitution using solar energy instead of fossil fuel	More expensive than conventional refrigeration process
Electricity saving compared to conventional technology	Depend on climatic conditions
Decrease electricity consumptions cost	Level of maturity varied
Panels easy to implement	Need to an alternative cold production in case of bad weather
	Low energy storage capacities

References

[1] Solar cooling technologies, S. Ajib and A. Alahmer

[2] Solar refrigeration options – a state of the art review, D.S Kim and C.A. Infante Ferreira

Refrigeration system improvement

Abstract

A company operating in high-quality meat production decides to carry out an energy efficiency assessment of their facilities to find inefficiencies. The main production is dedicated to cured ham, which must be made in compliance of specific food regulation requirements and under very specific temperature conditions to ensure the best product quality.

The assessment results underlined the need to change an old refrigeration system using R22 by a new centralized ammonia (NH_3) with the aim of reducing energy costs and emissions. The new system also allows better control of humidity and temperature which improve product quality, and a savings in the operating and maintenance costs, with a reduced pay-back period.

Category

Change refrigeration system

Level of collaboration

None

Results

- Investment: 300,000 €
- Savings:
  - 55,000 k€/year
  - 350,000 kWh/year

Main NEBs

- Reducing greenhouse gas emissions
- Increased equipment life
- Product quality improvement

Description

One of the energy efficiency assessment results indicates the possibility to replace the traditional R22 cooling system by a new centralized ammonia system (NH_3, R717) which brings different benefits as improved efficiency, easier maintenance, emissions reduction and better production parameters control.
With this new technology it is also possible to exploit some of the heat produced in the processes improving even more the overall heating and cooling performance.
The heat recovery system is integrated in the overall system, thus providing an integrated performance of great interest for any factory demanding cold and heat.

Solution details

The new refrigeration plant needs less refrigerant load compared to the old machine because it is designed with a compression-evaporation centralized system that ensures more efficiency.
The old system was a plant constituted by a set of individual compressors with an average energy efficiency ratio (EER) of 1.30 that have been upgraded to a centralized and controlled system with EER 3.5.

Benefits

The new system with technical, control and heat recovery lead to many benefits. The most important one is a significant energy efficiency increase of the overall cooling and heating system, from less than 1.5 EER up to 3.5 EER, considering the heat recovery. With a consequent energy cost savings.
By environmental point of view, reducing the greenhouse emission is another important benefit. It has been obtained due to operation with low GWP refrigerant.
Other benefits are the increased lifespan, lower maintenance requirements and improved control system.

Opportunities and barriers

Opportunities	Barriers
Lower energy consumption	Cost for new equipment
Lower refrigerant leakages	
High food quality preservation	
Little maintenance required	

Calculation model

The calculations show costs and returns of this renovation, as well as the economic impact after the implementation of the new NH3 system. In order to be clear, the initial situation is directly compared with the final situation and a table of differences is shown broken down into the different key points of savings, using an average price of electricity and emissions taking into account their expected evolution.

	Initial situation	Final situation
Productive capacity [t/year]	900	900
Annual energy consumption [kWh/year]	1,402,285	1,029,277
Annual energy cooling consumption [kWh/year]	981,600	608,592
Annual economic energy expenditure [€/year]	184,285	135,265

Total investment (€)	300,000
Energy savings [kWh/year]	373,008
Average electricity price[€/kWh]	0,13142
Average emission price [€/tCO_2]	36
Emission reduction [tCO_2/year]	150
Energy economic saving (€)	49,020
Emission economic saving (€)	5,400
Total economic savings (€)	54,420
Return period (years)	5.5

References

[1] Kvalsvik K.H., Evaluation of Three Drying Models for Dry-cured Ham (2014)

[2] Kvalsvik K.H., Efficient energy systems for the dry-cured meat industry (2017)

Cooling distribution system optimization

Abstract

Cooling distribution system design and maintenance are the most important aspects to get maximum efficiency of the overall industrial cooling process. The efficiency of a cooling distribution system depends on two main factors:

- Preventing heat losses and equipment degradation by a good isolation of the cooling fluid distribution pipes;
- Reducing pressure losses and cavitation by optimization of the distribution pumps' controlling system.

It often happens that pumps work with at higher flow and pressure head than necessary, thus increasing the risk of pump cavitation.

Using differential pressure control solutions can help optimize the performance of variable speed pumps and avoid energy overconsumption.

Category

Refrigeration system

Level of collaboration

Low

Results

A well-balanced circuit can save up to 35% of energy consumption

Main NEBs

- Reduced heat losses and pressure drops
- Maintenance of the equipment
- Prevent degradation of the pipes
- Prevent overconsumption of the pumps

Description

A SME company produces about 2,500 tons/year of pasta and pasta products (lasagna, eggplant rolls, etc.).
The cold processes are a crucial part of the energy consumption of the company. They are used both for cooling of production areas and for finished products warehouses (fridges and freezers).
The company bought a new cold production unit in order to satisfy its growing needs and to be compliant with environmental regulation aiming at reducing the use of HCFC R22, harmful to the ozone layer, as a gas refrigerant (still used within the company in old refrigeration plants).
The situation was the occasion to adopt and install an energy efficient and optimized solution. The chosen cold production unit works with ammonia as the refrigerant gas and uses an intermediate fluid (glycol water) to distribute the cold to the different consumers of the company (cold rooms, machines, production and storage areas).

Solution details

For adjusting the control of the distribution pumps to the flow rate required by the circuit of glycol water, the pumps are fitted with frequency converters.
A good insulation of glycol water circuit pipes allowed to reduce heat losses and to avoid condensation and corrosion that are frequent in this distribution systems.
While the CO_2 exchange would allow to reuse from 1,500 to 2,000 tons of CO_2 per cycle, which represent from 16 % to 21 % of the overall emissions of the considered industrial installation.

Opportunities and barriers

Opportunities	Barriers
Reduced heat losses	Additional cost for maintenance of the equipment
Reduced pressure losses and cavitation	
Lower electric consumption and related cost	
Prevent degradation of the pipes	
Prevent overconsumption of the pumps	

References

[1] https://energie.wallonie.be/fr/optimisation-energetique-d-une-nouvelle-installation-de-production-de-froid-chezpastificio-della-mamma.html?IDC=8041&IDD=9775

Adjustment of cooling temperatures

Abstract

An analysis on the required cooling temperatures of your products is quick-win measure with a great energy costs saving potentials. As well as evaluating whether thermostats are set adequately, a product groups review and optimization related to different storage temperature could carry out energy efficiency improvements, especially if combined with implementation of an intelligent temperature management system.

Category

Refrigeration system

Level of collaboration

None

Results

3-5 % of less refrigeration consumption per °C

Main NEBs

Reduced effort due to temperature management system

Description

An easily executable and low-cost action to reduce energy consumption for refrigeration by optimizing the refrigerant load in warehouses is the analysis of the required storage temperatures of each refrigerated or frozen product and the appropriately setting of thermostats.

Setting temperature

Many frozen food products must be kept below -18°C. Due to freezers doors opening or for high ambient temperatures, often manufacturers set their thermostats to -23°C or lower to get a safety margin. But each extra cooling degree requires additional energy consumption. By implementing new air curtains and freezer door seals and by accelerating of the opening and closing of freezer doors, some manufacturers accept a slightly warmer temperature of -21°C. Furthermore, refrigeration equipment has become way more efficient in recent years, so checking if your older rules on setting the temperatures still apply for the newer equipment can lead to significant energy savings.

Efficient product arrangement

Chill and frozen products arrangement can lead to reduction in energy consumption. Correct temperature setting taking into account the separation of different product groups, based on the same required storage temperature, can result in a 4% energy saving for chill temperatures and 2% for low temperatures by increasing the temperature.

Table [1] shows an overview on optimal storage temperatures for different product groups. Whenever possible, cooling at lower temperatures than required should be avoided, as each degree of decreased temperature increases the energy consumption by an order of magnitude of 3-5%.

Example: Intelligent temperature management saves electricity, costs and effort

A company, operating in ice cream and frozen specialties industry, implemented an intelligent temperature and energy management system for their sales vehicles to reduce energy consumption and to increase its sustainability.

The company performs their activities in compliance compliance with the closed deep-freeze chain right up to the domestic freezers guaranteeing its customers the full quality preservation. Therefore, the cooling load of about 3,000 sales vehicles that leave for the 2.5 million customer households every day requires a lot of energy. The temperature of the sales vehicles was previously controlled manually to -36°C, but the new temperature management system regulates the temperature of the refrigerated compartments at a constant level according to the residual cold and outside temperature. Each vehicle is monitored about core and air temperature in the cooling structure, the data are transmitted to a PC in the respective branch. The management program then calculates cold load that each vehicle will need for the next day considering the weather forecast. This minimizes the effort required for temperature monitoring because previously the temperature had to be read and transmitted manually from vehicles every day while now all is done by the measuring module. In case of temperature deviations, it immediately gives an alarm.

Food products	Optimal storage temperature [°C]
Deep frozen food	
Meat	-25
Poultry	-24
Fish	-29
Fruits and concentrated juices	-18
Vegetables	-18
Frozen food	
Frozen butter	-20
Chilled food	
Fresh meat	-1.5
Meat products	-2
Manufacturing meat	-2
Poultry	-1.5
Fish	In melting ice (-0.5 to 0)
Dairy products	0 to 2
Fruit and vegetables	
Low temperature (apple, blueberry, lettuce, etc.)	0 to 2
Moderate temperature (pumpkin, melon, etc.)	6 to 9
High temperature (banana, cucumber, etc.)	12 to 16

Table [1]: Optimal storage temperatures of various food products

Opportunities and barriers

Opportunities	Barriers
Improved product quality	New equipment for intelligent temperature management needed
Reduced effort for temperature control with intelligent temperature management	

Can be implemented already at minor costs (by reorganising the way product groups with different temperature needs are stored)	

References

[1] Cool-Save Project, Best practice guide on how to save energy in food and drink companies' cooling systems,

[2] Swedish Association for Frozen and Regriferated Foods, Correct temperature during storage and transport, 2016.

[3] https://www.resourceefficient.eu/en

[4] JRC (EU), Best Envionmental Management Practice for the Food and Beverage Manufacturing Sector. 2018.

[5] Publications Office of the European Union, Best Available Techniques (BAT) Reference Document for the Food, Drink and Milk Industries. 2019.

Separated compartments warehouse

Abstract

With the aim of improving the energy efficiency of a food retailer warehouse, a compartmentalization of the volumes was carried out along with other solutions. Foods that need to be stored at one temperature are kept in the same compartment. In this way, a lot of energy can be saved as it is not necessary to cool the entire warehouse to the lowest temperature required but only some compartments. Furthermore, the division of the warehouse can also reduce heating by heat convection due to the opening of the doors, only a small area of the warehouse will need to be re-cooled.

An HVAC expert (Heating, Ventilation and Air Conditioning) was involved to plan and design this solution. When implementing this, the separation of the compartments was optimized so that the compartments with a higher cooling temperature are arranged near the external walls of the warehouse, while those with a lower temperature are located towards the inside in order to minimize the thermal delta with the outside.

Category

Building

Level of collaboration

None

Results

Reduced energy consumption

Main NEBs

- Saving costs
- Green image

Description

The first analysis concerned the types of goods to be stored and the temperature required for each of them. Based on Table 1 (derived from German Federal Institute for Consumer Health Protection and Veterinary Medicine [1]), the products have been grouped according to the required storage temperature.
In order to minimise heat transfer to the refrigerated areas, the frozen compartments are designed to be as far away from the external walls. Furthermore, by ensuring that the doors of the freezer areas do not lead to the outside but to other cooled areas with a higher temperature, the refrigeration capacity is not completely lost.
The office area is planned so that it does not border with frozen food compartments but in a corner of the warehouse, i.e. with two external walls, appears to be suitable.

Solution details

The purpose of this measure is to minimize unwanted incoming heat to the cooled areas, for reducing the cooling load and energy (electricity) consumption.

Benefits

In addition to the main benefit of saving electricity, there are others that can be directly deduced from this, such as the reduction of the negative environmental impact of electricity generation (CO_2 emission) and an equivalent cost saving for the food trade.

T [C°]	Food products
-18	Frozen foods (except ice cream)
-12	Frozen meat, frozen egg products
+2	Fresh fish and fish products
+4	Fresh poultry meat, Hares, game and domestic rabbits, minced meat (products), feathered game, egg products
+7	Fresh meat (except poultry), game (except hare, and rabbits and feathered game), feathered game (pheasant, partridge, quail) even if they are farmed, gourmet salads, raw food (e.g. fresh mayonnaise)
+8	Preferential milk, chicken eggs
+10	Butter, cream cheese, dairy products, pasteurized milk, soft and semi-hard cheeses, live bivalve snails

Table 1: Maximum storage temperatures T for different food products in °C, based on [1]

Opportunities and barriers

Opportunities	Barriers
Lower power consumption and related cost	Know-how required
Greatest potential for new construction	Staff for planning required
Improved food quality	Limited implementability for existing warehouses
Negligible maintenance	Additional cost for glide racks
Green image	

References

[1] BGVV (Bundesinstituts für gesundheitlichen Verbraucherschutz und Veterinärmedizin, German Federal Institute for Consumer Health Protection and Veterinary Medicine) https://files.dreamway.com/filer/186/2011/1/31/temperatur.pdf.

Energy storage systems

Abstract

With the aim of reducing the environmental impacts due to the refrigeration of warehouses for food preservation, new technologies are emerging to increase performance and sustainability of these systems. Electrical energy storage (EES) and thermal energy storage (TES) systems recently gathered a large interest among the energy market.

By using EES and TES as part of an integrated system, overall efficiency can be improved resulting in less energy consumption. These technologies take on a key role in increasing and guaranteeing the storage capacity of energy from renewable sources.

These solutions decrease energy consumption, reduce carbon emissions, and saves money. They also lead to increased share of self-consumption and improved reliability.

Category

Energy generation

Level of collaboration

None

Main NEBs

- Reduced carbon emission
- Increased host capacity of RES
- Increased self-consumption
- Improved reliability

Description

In a world that is increasingly pushing towards sustainability and more decarbonized energy systems, Distributed Generation (DG) from Renewable Energy Sources (RESs) equipped with Energy Storage System (ESS) are having particular attention. ESS solutions, allowing to store energy and release it when needed, are a technology for abating the drawbacks of renewable energy caused by its intermittency and uncertainty.

They are also installed to overcome the mismatch between demand and supply of electrical or thermal energy when renewable energies are not enough.

The most promising ESSs for the cold chains are electrochemical (e.g., batteries) and thermal energy storage systems. Adding a battery increases, of course, cost and complexity of the system (i.e., photovoltaic plant) and reduces its steady-state efficiency.

Electrical storage may not be needed in a solar refrigeration system as thermal storage (e.g. ice or other low temperature storage mediums) could be more efficient and less expensive [1].

Benefits

Integration of Energy storage technologies with RESs guarantees energy security and climate change goals by [2]:

- improving efficiency of energy system resource
- helping to integrate higher levels of variable renewable resources and end-use sector electrification
- supporting greater production of energy where it is consumed
- increasing energy access
- improving electricity grid stability, flexibility, reliability and resilience.

Electrical Energy Storage

The main applications of EESs in cold value chains allow to shift refrigeration loads from peak to low consumption periods, reducing the purchase of energy and consequently costs and fossil fuel emissions for its production [3]. However, benefits and return of the investment depend on the electricity tariff [4]. The spread of these systems is limited by different barriers, in spite of the improved reliability and the more cost-competitiveness. Most important impediments are the lack of knowledge and awareness and other social, organizational or political factors [5].

Thermal Energy Storage

Thermal energy storage (TES) is an efficient system for reducing consumption of the cold chain. TES serves as a battery for refrigeration systems, using phase change material (PCM) to store thermal energy in the form of cold for future use.

TES modules containing PCM are placed above the storage racking so that they are above the product and are also placed inside the air stream of the evaporator fans.

This allows heat to flow via convection to the TES when the air units are off. Once the TES reach their thermal capacity absorbing heat, the air flow from the evaporator fans can efficiently and directly cool the calls back to the solid state. The PCM in the TES system provide latent heat capacity to the refrigerated environment, allowing the TES to absorb a large amount of thermal energy from the surrounding environment while remaining at the same temperature. This allows the refrigerated environment to maintain a cold operating temperature for an extended time period without running the mechanical systems.

During off-peak time, the PCM are frozen by existing refrigeration equipment, while during peak hours, PCM are used to maintain the temperature and to drastically reduce the mechanical run time of refrigeration systems. During these extended periods, the PCM:

- absorbs up to 85 percent of all heat infiltration in the freezer
- maintains 38 percent more stable temperatures to ensure food quality and safety,
- helps avoid up to 90 percent of peak period consumption

If integrated with renewable power sources TES can reduce overnight grid power up to 95%. This helps facilities further reduce their grid-based energy consumption and contribute to sustainability and renewable energy goals.

Cryogenic Energy Storage

Liquid Air Energy Storage (LAES) is a technology that allows to reduce fossil fuel usage in food industry for refrigerating and for increasing energy system flexibility [6]. Cryogenic Energy Storage (CES) is a thermal energy storage principle not fully developed, but it turns to be interesting for its features and advantages [7]. At low power demand, CES systems use electricity from RES or the grid to liquefy a mixture of separate nitrogen, oxygen and argon, and to store the liquefied cryogen in a large insulated vessel at very low (cryogenic) temperatures. It can be recalled that, at atmospheric pressure, liquid nitrogen (constituting approx. 78% of the air content) has a boiling point of -195.8 °C, while liquid oxygen (approx. 21% of the air content) boils at -183 °C. The latent heat of vaporization is 200 kJ/kg for N_2 and 213 kJ/kg for O_2. In several applications, a sensible heat of up to 160 kJ/kg can also be exploited.

CES acts as grid or RES energy storage depends on peak demands. The principle of Cryogenic Energy Storage is:

- During periods of low-power demand and low energy price, a cryogenic gas is liquefied and stored in a well-insulated vessel (charging period).

- During times of high-power consumption and high energy price, the liquefied cryogen is pumped and expanded to drive a generator of power which is restored to the electrical grid (discharging period).

The CES technology is not very widespread applications because of the poor round-trip efficiency (ratio between energies retrieved from and spent for energy storage) due to unrecovered energy losses. In fact, the liquefaction of a unit mass of cryogen currently consumes much more energy than its evaporation can deliver.

The CryoHub[2] project recently investigated the potential of largescale cryogenic energy storage at refrigerated warehouses and food factories, thereby capturing and utilising the vast amount of cryogenic cold released when boiling the stored liquid cryogen (in combination with RES integration and waste heat recovery). This extra cooling potential eases the functioning of existing refrigeration plants by providing substantial part of the refrigeration capacity needed to maintain the desired low temperatures in storage warehouses for chilled or frozen foods.

Furthermore, integrating CES into food processing or preservation facilities is a novel and attractive means for fostering the growth of the RES sector, revealing also a substantial potential to improve efficiency [7].

Opportunities and barriers

Opportunities	Barriers
Reduced energy bill	Investment cost
Reduced carbon emissions	
Increased host capacity of RES	
Increased self-consumption	

References

[1] S.A. Klein, D.T. Reindl, Solar refrigeration, ASHRAE J. 47 (2005). doi:10.1007/978-1-4471-1742-1_12.

[2] International Energy Agency (IEA), Technology Roadmap - Energy Storage, (2014).

[2] CryoHub “Cryogenic Energy Storage for Renewable Refrigeration and Power Supply” (2015) Horizon 2020 Project No. 691761

doi:10.1007/SpringerReference_7300.

[3] B. Marchi, S. Zanoni, M. Pasetti, A techno-economic analysis of Li-ion battery energy storage systems in support of PV distributed generation, in: Proc. Summer Sch. Fr. Turco, 2016: pp. 145–149. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85006056671&partnerID=40&md5=a4260adc9a31b61f4adbef6f8ba57141.

[4] B. Marchi, M. Pasetti, S. Zanoni, Effect of Demand Tariff Schemes in Presence of Distributed Photovoltaic Generation and Electrical Energy Storage, in: V. Murgul, M. Pasetti (Eds.), Adv. Intell. Syst. Comput., Springer International Publishing, 2020: pp. 201–215. doi:10.1007/978-3-030-19756-8_19.

[5] G. May, B. Stahl, M. Taisch, D. Kiritsis, Energy management in manufacturing: From literature review to a conceptual framework, J. Clean. Prod. 167 (2018) 1464–1489. doi:10.1016/j.jclepro.2016.10.191.

[6] D. Murrant, J. Radcliffe, Analysis of when and where the integration of LAES with refrigerated warehouses could provide the greatest value to Europe, Energy Procedia. 151 (2018) 144–149. doi:10.1016/j.egypro.2018.09.039.

[7] K. Fikiin, B. Stankov, J. Evans, G. Maidment, A. Foster, T. Brown, J. Radcliffe, M. Youbi-Idrissi, A. Alford, L. Varga, G. Alvarez, I.E. Ivanov, C. Bond, I. Colombo, G. Garcia-Naveda, I. Ivanov, K. Hattori, D. Umeki, T. Bojkov, N. Kaloyanov, Refrigerated warehouses as intelligent hubs to integrate renewable energy in industrial food refrigeration and to enhance power grid sustainability, Trends Food Sci. Technol. 60 (2017) 96–103. doi:10.1016/j.tifs.2016.11.011.

Annex 2 – NACE Codes

The project will target businesses in the food and road transport sectors, with a primary focus on NACE codes:

NACE Code	Description
C10	Manufacture of food products
C11	Manufacture of beverage
G46.3	Wholesale of food, beverages and tobacco
G47.11	Retail sale in non-specialised stores with food, beverages or tobacco predominating
G47.2	Retail sale of food, beverages and tobacco in specialised stores
H49.2	Freight rail transport
H49.41	Freight transport by road
H50.20	Sea and coastal freight water transport
H50.40	Inland freight water transport
H51.21	Freight air transport

REEVALUE

https://www.corkchamber.ie/international/reevalue/

@REEValue_EU

This project has received funding from the European Union's Environment and Climate Action (LIFE 2014–2020) programme under grant agreement No 101119828