

# Energy efficiency synergies in the dairy industry

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## Abstract

The European Union's dairy sector stands as the second-largest agricultural segment within the EU, comprising over 12 % of the overall agricultural output. Dairies exhibit significant energy consumption, contributing to indirect emissions. The dairy sector represents between 2 % to 4 % of the global emissions of greenhouse gases (GHG) per year.

Conventional dairy processes necessitate heating for milk processing and refrigeration for storage, posing a challenge in optimizing energy utilization. In this context, the importance of energy efficiency measures (EEMs) and the utilization of renewable energy sources (RES) becomes pronounced when viewed holistically, considering a coordinated supply chain. This approach is crucial for advancing sustainability across economic, environmental, and social dimensions.

Among the various EEMs, heat pumps that generate both hot water and cold air emerge as a promising avenue for substantial energy savings. They play a key role in reducing dependency on fossil fuels, primarily oil and gas, and in curbing greenhouse gas (GHG) emissions. The heat pumps recover heat from the compressor used in the milk production process, which otherwise would be released as condensation heat into the air if a heat pump were not employed.

This contribution aims to show how integrating heat pumps enables the efficient utilization of waste heat from refrigeration systems to fulfill heating requirements, establishing a synergistic relationship between the two processes.

## Introduction

Dairy products play an important role in providing nutrients and minerals for all households and benefiting all families of all ages. The increased production and consumption of raw milk and dairy products in various communities support this perception. However, dairies exhibit significant energy consumption, contributing to emissions in all phases which include supply, production, and distribution. The carbon footprint of European dairy production has significantly decreased since 1990 according to the Annual European Union greenhouse gas inventory 1990–2018. Despite these multiple benefits, most firms still face many difficulties and, in some cases, hostility when trying to implement energy efficiency plans. The most dominant of these barriers, especially for SMEs, are access to capital and lack of awareness. Supply chain management is one of the main ways to overcome those barriers; it can also support the implementation of energy efficiency measures for companies with a lower competitive positioning in the marketplace (Marchi and Zanoni, 2017). (Marchi et al., 2022) and (Marchi and Zanoni, 2022) analyzed the energy consumption of a dairy chain that produces cheese requiring refrigeration in each step of the cold chain (e.g., spreadable cheese or grated cheese). The required data were directly gathered through interviews with European companies in the dairy industry and/or logistic companies during the H2020 ICCEE project (Zanoni et al., 2020; Diaz et al., 2022). The results show that the highest energy contribution for refrigeration purposes per unit of product is due to the milk storage at the supplier and producer warehouses, also due to the huge quality losses since the raw material has not yet been processed.

The dairy manufacturing process represents one of the major situations where heating and cooling demands could oc-

cur simultaneously and could be satisfied by heat pumps using two thermal effects (cooling and heating) of a heat pump in a single device (Byrne et al., 2018). Heat pumps can transfer heat from a heat source to a heat sink using mechanical work. They can produce simultaneously heating and cooling energies to carry out energy savings. Simultaneous heat and cooling (SHC) heat pumps are a promising technology that can revolutionize the dairy sector by addressing energy efficiency, environmental sustainability, and cost-saving goals. Their versatile applications, coupled with their ability to utilize waste heat sources and integrate with renewable energy, make them a compelling choice for dairy farms and processing plants seeking to implement sustainable and efficient heating and cooling systems.

Some pilot applications exist. For instance, (Jordan et al., 2016) proposed a water-water heat pump for simultaneous cold and heat generations, and operational tests were performed with three heat-pump prototypes designed for dairy farms, at both laboratory and field levels.

Recently, Ayou et al (2022) investigated an ammonia-based heat pump that simultaneously deliver heat (65–95 °C) and cooling (2 °C) for the pasteurization of raw milk. The integrated heat pump systems performance simulations were carried out at the base-case design conditions and parametric study on the influence of key operational variables on the system's first- and second-law efficiencies. They showed that heat pumps investigated are more efficient solutions than current heating and cooling systems used in the dairy processing industries (fossil-fuel fired boiler and ammonia compression chiller) by up to 59 % of a primary energy saving.

The example demonstrates that SHC heat pumps can be a valuable tool for dairy farms looking to reduce their energy consumption and environmental impact.

The technology is becoming increasingly affordable and efficient, and it is likely to play an increasingly important role in the dairy sector in the years to come. As the technology continues to develop and mature, widespread adoption of SHC heat pumps in the dairy industry can be expected, paving the way for a more sustainable and environmentally responsible dairy production system. Furthermore, heat pumps can be seamlessly integrated with renewable energy sources, such as solar panels or geothermal energy, to create a sustainable energy system for dairy operations. This further reduces reliance on fossil fuels and enhances the environmental benefits of heat pump technology.

This study is focused on the production phase: collected raw milk requires several processing steps to become final products, which include a multi-stage production system, including pasteurization, sterilization, and seasoning storage. The present work aims to study how SHC heat pump technology can improve the energy and environmental performance of dairy companies leading to a zero-carbon industry and to investigate real use cases through the discussion of pilot projects with high TRL. The remainder of the paper is organized as follows: first, insights into the dairy sector are provided in terms of economic and environmental performances and sustainability. Then, the focus is moved to the potential of heat pumps in dairy companies, specifically, for cases with simultaneous demand for heat and cooling. The next section proposes potential use cases where SHC heat pumps can be beneficial in the dairy sector.

The last section draws on the main findings of this work and identifies potential future research topics.

### Dairy sector and its environmental impact

The current agri-food sector faces significant challenges across the world. Major concerns about sustainable production, a growing population, and entrenched nationalism are putting a strain on the status quo. In response to the urgency of the situation and citizen demand, in December 2019, the European Commission, within its communication on the Green Deal, committed to transforming the EU into a “fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of GHG by 2050 and where economic growth is decoupled from resource use”. The Green Deal also aims at protecting, conserving, and enhancing the EU's natural capital and protecting the well-being of citizens from environmental risks. It is in this context that the dairy sector globally has made ambitious long-term commitments to contribute to the Sustainable Development Goals (SDGs), such as ending poverty and hunger and protecting the environment. This was set out in the 2016 “Dairy Declaration of Rotterdam” by the International Dairy Federation and the Food & Agriculture Organization of the United Nations. Other several initiatives are underway to promote sustainability in the dairy sector and reduce energy consumption. These include the EU Sustainable Dairy Platform which brings together dairy stakeholders to develop and implement sustainable dairy policies; RE100 global initiative which encourages companies to commit to sourcing 100 % of their electricity from renewable sources; and the dairy carbon footprint initiative which provides tools and resources for dairy farmers to measure and reduce their greenhouse gas emissions.

To realize a large-scale transition, significant efforts from across the value chain are necessary. At the same time, the sector is restricted in its ability to work towards long-term goals by the immediate challenges in the economic, social, environmental, and climate spheres. Volatile product prices and pressure to increase and intensify production, driven by export markets coupled with consumer expectations for more environment and climate-friendly products, high animal welfare, and local production systems have put increasing pressure on the sector.

The EU dairy sector is the second biggest agricultural sector in the EU, representing more than 12 % of total agricultural output. The EU dairy sector is faced with several socio-economic challenges, including fluctuating market prices, high labor costs, and aging demographics. The number of dairy farms has declined across Europe (a decrease of 1.2 million farms between 1983 and 2013 in the EU-10), as fewer farms are passed on to the next generation – small-scale farms are particularly affected. Raw milk and dairy price volatility have both increased significantly during the last decade. Since 2007, the magnitude of price variation has increased with most years seeing strongly fluctuating raw milk and dairy prices. This led to an unsustainable situation for many farmers who received a price for their milk far below their production costs. By producing at a loss over a long period, many farmers were struggling to survive, sometimes even facing bankruptcy.

All 28 Member States produce milk. The main producers of cow milk are Germany, France, the United Kingdom, the Neth-

erlands, Poland, Italy, and Ireland, which together account for three-quarters of total EU production. Most of the produced milk (approximately 90 %) is delivered to dairies for further processing, the rest being used in other ways on the farms (either consumed, processed, directly marketed, or used as feed). In 2017, around 156 million tons of cows' milk were delivered to EU dairies. Around 12,000 processing plants are employing 300,000 people in the EU. The dairy sector is predominantly organized in cooperatives, which hold a 55 % market share. These cooperatives can be as large as world-leading multinational companies or as small as SMEs or micro-enterprises. Whereas the three largest companies in the EU dairy sector are investor-owned firms, the next four are cooperatives.

Facing several challenges, the EU dairy sector must become more resilient and sustainable. From an economic point of view, it is necessary to lower production costs to improve competitiveness, while also increasing the economic resilience of dairy farms confronted with high price volatility and market uncertainty. At the same time, the dairy sector must be more efficient in the use of natural resources such as water and feed and do more to control the environmental impact of breeding activities (reducing greenhouse gas emissions, water pollution, etc.). Resilient dairy farming also means taking good care of herds and meeting health requirements. A 2018 EIP-AGRI report explores three key areas through which to achieve robust and resilient production systems. At the level of the cow, genetics and precision livestock farming are areas with a high potential to enhance robustness and resilience. At the level of the farm, the report looks at ways to increase the capacity of a farm to absorb impacts caused by changes in environmental, social, or economic conditions. Finally, for the dairy sector, the report identifies the essential role of information, communication, and dialogue between farmers and consumers, which requires better knowledge and understanding of dairy production and better ways to benchmark it, as well as proper translation of this in a way that the final consumer can understand and appreciate.

All farming systems are intrinsically tied to the climate and functioning of a healthy natural environment. The EU dairy sector is both a victim of and contributes to climate change. Farming in the EU is responsible for just over 10 % of economy-wide greenhouse gas (GHG) emissions. Most emissions of non-CO<sub>2</sub> greenhouse gases (i.e., methane and nitrous oxide) in agriculture originate directly or indirectly from animal production; in a business-as-usual scenario, this sector would be directly responsible for 72 % of economy-wide non-CO<sub>2</sub> emissions in 2030. Yet, the sector is also one of the first victims of climate change and, indeed, changing weather and climate patterns leading to disease outbreaks, animal heat stress, worsened reproductive performance, decline in water resource availability, and reduction of soil fertility. Addressing the mitigation challenge correctly should enable greater resilience in the sector and across the supply chain, providing longer-term sustainability as well as improved efficiency and cost-saving on farms and in the production process. Climate change challenges also exacerbate the degradation of many ecosystems that happened over the last decades. Whilst some farming practices are essential to the maintenance of certain types of habitats, farming remains among the most significant contributors to biodiversity decline in the EU. Conventional production and process-

ing practices can impact water availability, as well as water and soil quality. Given the great reliance of farming on healthy and productive natural resources, this degradation is a direct threat to long-term food security and future production.

The dairy sector represents between 2 % to 4 % of the global emissions of greenhouse gases (GHG) per year, according to the FAO report on Greenhouse Gas Emissions from the Dairy Sector.

Dairies have a significant energy consumption which also generates indirect emissions. Around 60 %–80 % of the energy is consumed as thermal energy from the combustion of fossil fuels to generate steam and hot water. It is used for heating operations and cleaning. The remaining 20 %–40 % is consumed as electricity to drive machinery, refrigeration, ventilation, and lighting. The most energy-consuming operations are the evaporation and drying of milk. Energy audits conducted in 2010 have shown that electricity usage contributes on average 60 cents/liter to milk production costs, which in some cases are higher than the milk price.

The dairy sector is a significant contributor to environmental impacts and energy consumption. Dairy production processes, from raising cows to processing milk, generate greenhouse gases, pollute water bodies, and consume energy. Understanding these environmental impacts is crucial for developing sustainable practices in the dairy industry. Dairy cows emit methane, a potent greenhouse gas, as a by-product of their digestion process. Methane emissions from dairy cattle account for approximately 3 % of global methane emissions, contributing to climate change. Additionally, manure management practices, such as storage and spreading, can release methane and nitrous oxide, further exacerbating the greenhouse effect. Dairy farming operations can pollute water bodies through direct and indirect means. Manure runoff from pastures and concentrated animal feeding operations can contaminate surface water with nutrients, causing eutrophication, which depletes oxygen levels and harms aquatic life. Additionally, the application of fertilizers and pesticides used in dairy crop production can leach into groundwater, posing a threat to drinking water quality. The dairy industry consumes substantial amounts of energy throughout the production process. This includes energy used for milking machines, refrigeration, transportation, and processing equipment. Additionally, energy is required to produce feed, fertilizers, and other inputs used in dairy farming. The main environmental drawbacks of dairy production are reported in Table 1.

The dairy sector is a significant energy consumer in Europe, accounting for approximately 4 % of the EU's total primary energy consumption. This is due to the energy-intensive nature of dairy production processes, which include raising cows, processing milk, and transporting and distributing dairy products. The main drivers of energy consumption in the dairy sector can be categorized into three main areas:

- **Farming Operations:** Dairy farms consume energy for various activities, including milking machines, refrigeration, ventilation, heating, and lighting.
- **Processing and Manufacturing:** Dairy processing plants consume energy for a variety of processes, including pasteurization, homogenization, drying, packaging, and transportation.

**Table 1. Main environmental drawbacks of the dairy production.**

<b>Greenhouse gas emissions</b>	
Methane Emissions from Ruminants	Cows and other ruminant animals produce methane as part of their digestive process. Methane is a potent greenhouse gas with a global warming potential 25 times greater than carbon dioxide. Dairy farming is responsible for approximately 14 % of global methane emissions.
Nitrogen Oxide Emissions from Manure Management	Manure from dairy cows contains high levels of nitrogen. Improper manure management, such as open storage or inadequate application of manure to fields, can lead to the release of nitrogen oxide, another potent greenhouse gas.
<b>Water Pollution</b>	
Nitrate Pollution from Manure Runoff	Manure runoff from dairy farms can contaminate surface waters with nitrogen and phosphorus, leading to eutrophication, a condition that can kill aquatic plants and animals.
Pathogen Contamination from Manure Runoff	Manure runoff can also carry harmful pathogens that can contaminate drinking water sources and pose health risks to humans.
<b>Land degradation</b>	
Soil Erosion from Intensive Grazing	Intensive grazing practices can lead to soil erosion, which can reduce soil fertility and biodiversity.
Loss of Biodiversity	Dairy farming can contribute to the loss of native plants and animals, as it can fragment habitats and alter ecosystems.
<b>Energy consumption</b>	
Dairy Production Requires Significant Energy	The dairy industry is a major energy consumer, with energy used for various purposes, including milking machines, refrigeration, ventilation, heating, lighting, and transportation.
Dependency on Fossil Fuels	The dairy industry relies heavily on fossil fuels for its energy needs, which contributes to air pollution and greenhouse gas emissions.

- **Transportation:** Transportation of raw milk and dairy products accounts for a significant portion of the sector's energy consumption.

The breakdown of energy consumption by stage of the dairy production chain is as follows: farming operations (40 %), processing and manufacturing (35%), and transportation (25 %). The primary energy sources used in the dairy sector in Europe are natural gas (35 %), electricity (30 %), fossil fuels (15 %), and renewable energy (20 %).

There are several reasons why heat and refrigeration are essential in the various stages of dairy production, defined in Table 2. By addressing the need for heat in the various stages of dairy production, the industry can ensure the optimal environment for cows, maintain product quality, and preserve the safety of dairy products for consumers.

Energy consumption in the EU dairy sector has been relatively stable in recent years, with some fluctuations due to economic conditions and changes in energy prices. However, there is a growing trend towards increasing energy efficiency and reducing reliance on fossil fuels. This is due to several factors, including:

- **The rising cost of energy:** the cost of fossil fuels has been increasing in recent years, making energy efficiency a more attractive option for dairy farms and processing plants.
- **The EU's renewable energy targets:** the EU has set ambitious targets for increasing the use of renewable energy, which is making renewable energy sources more cost-competitive with fossil fuels.
- **Consumer demand for sustainable products:** consumers are increasingly demanding sustainable products, and dairy producers are responding by adopting more sustainable practices, including reducing their energy consumption.

In this context, EEMs and RES from a holistic perspective (i.e., considering a coordinated supply chain) acquire great relevance to pursue sustainability on the three dimensions: i.e., economic, environmental, and social (EC-JRC, 2015 and 2019). Among the EEMs, heat pumps producing both hot water and cold air represent huge potential in energy savings, in the reduction of fossil fuels dependency (mainly oil and gas), and in the reduction of GHG emissions. Heat is recovered from the compressor used in the production process that cools the milk. Without the use of a heat pump, the condensation heat is simply left to evaporate into the air. It is reasonable to assume that there is potential savings of up to 75 % savings. To mitigate the environmental impacts of dairy production, various sustainable practices are being implemented. These include:

- **Improving energy efficiency in farming operations:** this could involve using more efficient milking machines, upgrading lighting systems, and implementing better insulation.
- **Optimizing processing and manufacturing processes:** this could involve using more efficient heat exchangers, implementing heat recovery systems, and switching to energy-efficient packaging materials.
- **Enhancing transportation efficiency:** this could involve optimizing delivery routes, using more fuel-efficient vehicles, and investing in renewable energy sources for refrigeration.

Here are some specific examples of energy-saving measures that are being implemented in the EU dairy sector:

- **Dairy Farm in Sweden:** Arla, a Swedish dairy company, has installed SHC heat pumps at several of its farms. The heat pumps have reduced the farms' energy consumption by up to 50 %.

- Dairy Processing Plant in Germany: Müller, a German dairy company, has installed SHC heat pumps at its processing plant in Nördlingen. The heat pumps have reduced the plant's energy consumption by 30 %.
- Dairy Farm in New Zealand: Fonterra, a New Zealand dairy company, has installed a 2MW SHC heat pump at one of its dairy farms. The system is expected to save the farm around \$100,000 per year in energy costs.
- Dairy Processing Plant in the United States: Dean Foods, a US dairy company, has installed SHC heat pumps at several of its processing plants. The heat pumps have reduced the plant's energy consumption by up to 20 %.

These examples demonstrate that there are several effective technologies available to reduce energy consumption in the dairy sector. By adopting these measures, dairy producers can lower their operating costs, reduce their environmental impact, and contribute to a more sustainable future.

### Typical energy consumption of dairy plant

Typical hard cheese is produced by heating milk to a temperature around 50–60 °C, at which it must be kept for about 1 hour and a half. Usually, heating, and subsequent maintenance at

temperature are carried out by using steam produced using gas-fired boilers. At the end of the heating interval, the cheese is extracted (just around 10 % of the total incoming mass), and the remaining whey, available at about 50–55 °C, is cooled to about 10 °C and then sold. The typical whey cooling process consists of cooling with an ice-water heat exchanger. It should be noted that excess heat from the whey cooling process can be eventually reused elsewhere in the dairy, such as in pre-heating water for cleaning or other heating requirements even if in this case it would require the synchronisation of the different activities that usually occur at different times during the day.

In medium-larger dairies, cogenerators with gas-fired combustion engines are widely used in Italy also thanks to the incentives scheme. In addition, in the dairies, there is a non-negligible consumption of domestic hot water, used both for bathrooms and showers for staff use and for sanitizing the rooms (that can represent up to 5–10 % of the total energy).

Another source of consumption is linked to the ripening phase, which can require a stay of 6–12 months at temperatures of the order of 16–18 °C.

Due to the high dehumidification load caused by the cheese maturing process (the cheese releases water in the air), the air is very often cooled down to condensation conditions (9–11 °C) and then the air must be heated up again at a maximum tem-

Table 2. Main reasons why heat and refrigeration are essential in the various stages of dairy production.

<b>Farming operations</b>	<ul style="list-style-type: none"> <li>• Maintaining a comfortable environment for cows: Cows are most productive in a comfortable environment with temperatures ranging from 7 °C to 18 °C. Heating barns during cold weather ensures that cows have a suitable environment for milk production.</li> <li>• Heating water for milking: Milking parlors require warm water for cleaning and sanitizing equipment and for washing cows' udders before milking. Heating water for these purposes is essential for maintaining hygiene and preventing infections.</li> <li>• Drying manure: Drying manure is a common practice on dairy farms to reduce odor emissions and improve manure management. Heating manure to a certain temperature helps speed up the drying process and reduce the volume of manure to be stored or transported.</li> <li>• Milk storage: Milk is a highly perishable product that must be kept cool to preserve its quality and safety. Refrigerated storage tanks are essential for maintaining milk at temperatures between 1 °C and 3 °C throughout the milking process and during transport to processing plants.</li> <li>• Dairy product storage: Dairy products like cheese, yogurt, and butter are also susceptible to spoilage and must be kept refrigerated to maintain their freshness and quality. Refrigerated storage rooms and display cases are essential for ensuring the proper preservation of these products.</li> </ul>
<b>Processing and Manufacturing</b>	<ul style="list-style-type: none"> <li>• Pasteurization and homogenization: Pasteurization and homogenization are essential processes in dairy processing, ensuring the safety and consistency of dairy products. Both processes require heating liquids to specific temperatures, making heat a crucial component of these operations. Moreover, pasteurization is a heat treatment process that eliminates harmful bacteria from milk and other dairy products. Refrigeration is crucial for maintaining the temperature of the milk during the pasteurization process to ensure effective microbial inactivation. Homogenization breaks down fat globules in milk, resulting in a smoother texture and improved shelf life. Refrigeration is necessary to maintain the proper temperature of the milk during the homogenization process.</li> <li>• Lactofermentation: Lactofermentation is a natural fermentation process used to produce yogurt, cheeses, and other dairy products. This process requires maintaining specific temperature conditions, often around 32 °C to 46 °C, to promote the growth of beneficial bacteria.</li> <li>• Drying dairy products: Drying dairy products like cheese, milk powder, and whey concentrates reduces their moisture content and extends their shelf life. Heating these products to high temperatures is necessary for efficient drying and maintaining product quality.</li> <li>• Packaging: Refrigeration is often used to chill packaging materials before filling, which helps prevent spoilage and ensures the integrity of the packaging. This is particularly important for products that are sensitive to moisture or temperature changes.</li> </ul>
<b>Transportation</b>	<ul style="list-style-type: none"> <li>• Refrigerating milk and dairy products: Maintaining a cold temperature throughout the transportation chain is critical for preserving the quality and safety of milk and dairy products. Refrigerated trucks and trailers play a vital role in transporting these products to distribution centers and retail outlets.</li> </ul>

perature of 23–25 °C in winter. The heating is usually powered by steam or hot water from a dedicated gas boiler.

Looking at the energy consumption of a medium dairy located in Italy to produce hard cheese (Grana Padano) the following figure reports the gas consumption (entirely used in boilers to produce steam) and electrical consumption (80 % used for refrigerated ice-water production for cooling whey and keep seasoning warehouse at the proper conditions). It should be observed that the Specific energy consumption in the production of cheese in the Best Available Techniques (BAT), Reference Document in the Food, Drink and Milk Industries (EC-JRC, 2015 and 2019) is equal to 0.2 MWh/raw materials.

As can be seen from Figure 1, although there are some seasonal variations the portion of heating and refrigeration consumptions are comparable and the lack of heat recovery in the greater part of dairy farms highlights the untapped potential of applying combined heat and cold generation with heat pumps for energy-efficient cheese production.

### Synergies in the energy flows

Heat pumps play a critical role in the dairy sector, offering a sustainable and energy-efficient solution for heating and cooling applications. They can be used for various purposes in dairy farms and processing plants, contributing to both environmental and economic benefits. On dairy farms, heat pumps are particularly effective for providing space heating and water heating. They can utilize waste heat from cow manure or other sources to generate hot water for cleaning and sanitizing equipment, reducing reliance on traditional boilers and fossil fuels. This can significantly lower greenhouse gas emissions and energy costs.

Heat pumps can also be employed for cooling applications in dairy processing plants, particularly for cooling milk storage tanks. They can effectively capture heat from the milk and transfer it to a refrigerant, ensuring that the milk stays at a safe and consistent temperature throughout the processing stages.

This reduces the need for traditional refrigeration systems and their associated energy consumption.

The adoption of heat pumps in the dairy sector offers numerous economic advantages, including:

- **Reduced energy costs:** heat pumps are highly efficient and can lower energy consumption by up to 60 % compared to traditional heating and cooling systems. This translates into significant savings on energy bills.
- **Lower greenhouse gas emissions:** by reducing reliance on fossil fuels, heat pumps help to minimize greenhouse gas emissions, contributing to environmental sustainability.
- **Improved energy efficiency:** heat pumps can help dairy farms and processing plants achieve compliance with energy efficiency regulations and improve their overall energy performance.
- **Extended equipment lifespan:** heat pumps can distribute heat or cold more evenly, extending the lifespan of equipment and reducing maintenance costs.

The use of heat pumps in the dairy sector aligns well with the broader sustainability goals of the industry. By reducing energy consumption and greenhouse gas emissions, heat pumps contribute to a more sustainable dairy production system. They also promote energy efficiency and reduce reliance on traditional energy sources, supporting the industry's transition to a cleaner and more environmentally responsible future, especially when the heat pump is powered by renewable electricity.

Simultaneous heat and cooling heat pumps are emerging as a promising technology in the dairy sector, offering several advantages over traditional heating and cooling systems. They provide a versatile solution for meeting the diverse temperature control needs of dairy farms and processing plants, contributing to energy efficiency, environmental sustainability, and cost savings. Advantages of SHC Heat Pumps in the Dairy Sector:

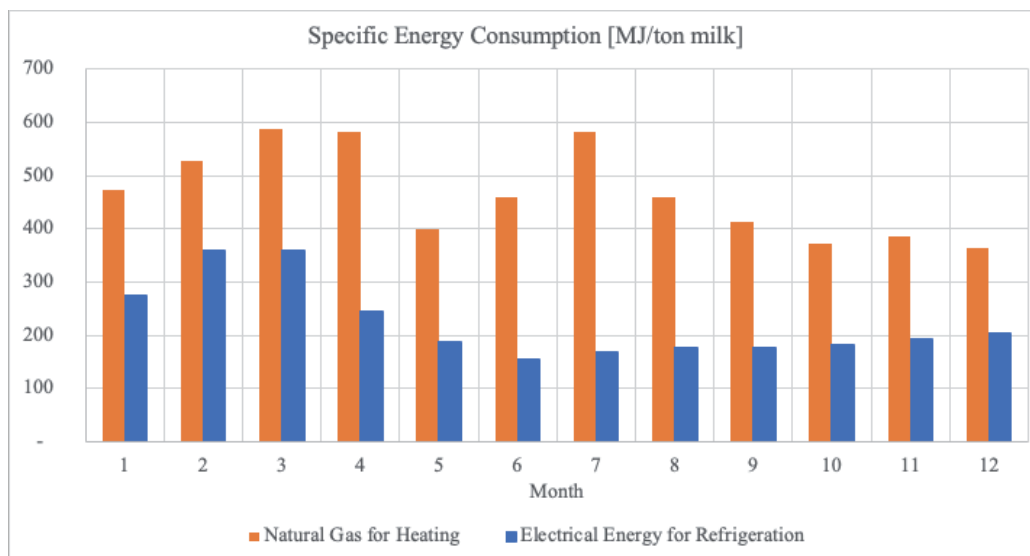


Figure 1. Natural Gas and Electrical Energy specific energy consumptions over a year for a typical medium dairy producing and seasoning hard cheese.

- **Efficiency and Energy Savings:** SHC heat pumps operate on a more efficient thermodynamic cycle compared to traditional heating and cooling systems. This translates into significant reductions in energy bills and operating costs for dairy operations.
- **Sustainability and Environmental Benefits:** by reducing reliance on fossil fuels, SHC heat pumps minimize greenhouse gas emissions, contributing to a more sustainable dairy production system. They also promote energy efficiency and reduce reliance on traditional energy sources, aligning with the industry's transition to a cleaner and more environmentally responsible future.
- **Versatility and Flexible Applications:** SHC heat pumps can effectively fulfill both heating and cooling requirements in dairy farms and processing plants. This flexibility caters to varying temperature needs throughout the day, reducing the need for separate systems and promoting efficient energy utilization.
- **Utilization of Waste Heat Sources:** SHC heat pumps can harness waste heat from various sources, such as wastewater, refrigeration systems, or even ambient air, as a renewable energy source. This reduces the reliance on fossil fuels and minimizes environmental impact.
- **Improved Indoor Climate Control:** SHC heat pumps can effectively control humidity levels and air quality, creating a comfortable and healthy working environment for dairy employees. This contributes to improved productivity and reduced sick leave.
- **Reduced Maintenance Costs:** SHC heat pumps have a simplified design and fewer moving parts compared to traditional systems, leading to reduced maintenance costs and extended equipment lifespan.
- **Integration with Renewable Energy Sources:** SHC heat pumps can be seamlessly integrated with renewable energy sources, such as solar panels or geothermal energy, to create a more sustainable energy infrastructure for dairy operations.
- **Contribution to Industry Sustainability Goals:** the adoption of SHC heat pumps aligns with the broader sustainability goals of the dairy industry, promoting energy efficiency, reducing environmental footprint, and fostering a more sustainable dairy production system.

SHC Heat Pump has a broad application scope in the dairy sector, some examples are:

- **Space Heating and Cooling for Dairy Barns:** SHC heat pumps can provide efficient and comfortable temperature control in dairy barns, maintaining optimal conditions for both cows and workers.
- **Milk Storage Tank Cooling:** SHC heat pumps can effectively cool milk storage tanks, maintaining the milk at a safe and consistent temperature throughout the processing stages.
- **Processing and Pasteurization Heating:** SHC heat pumps can provide precise heating for various processes, such as pasteurization and homogenization, utilizing waste heat sources to reduce energy consumption.
- **Condensation Control and Evaporative Cooling:** SHC heat pumps can effectively remove excess moisture from air ducts and processing areas, preventing condensation, and maintaining a comfortable working environment for employees.
- **Integrated Air Conditioning Systems:** SHC heat pumps can be integrated into comprehensive air conditioning systems to control temperature, humidity, and air quality throughout dairy processing plants.
- **Heat Recovery from Refrigeration Systems:** SHC heat pumps can effectively recover heat from refrigeration systems, utilizing this waste heat for space heating or preheating water, reducing energy consumption.

### SHC heat pump use cases in the dairy sector

In Sweden, dairy company Arla has installed SHC heat pumps at several of its farms. The company has found that the heat pumps have reduced their energy consumption by up to 50 %. This has led to significant cost savings for the farms and has also helped to reduce their environmental impact. Arla's SHC heat pumps are used for a variety of applications, including space heating, water heating, and cooling. The heat pumps can operate efficiently even in cold climates, and they can also utilize waste heat from the farms' operations. The implementation of SHC heat pumps has resulted in several benefits for Arla's farms, including:

- **Reduced energy consumption:** as mentioned above, the heat pumps have reduced the farms' energy consumption by up to 50%. This has led to significant cost savings, which have been passed on to Arla's customers.
- **Reduced greenhouse gas emissions:** by reducing energy consumption, the heat pumps have also helped to reduce the farms' greenhouse gas emissions. This is in line with Arla's commitment to sustainability.
- **Improved working conditions:** the heat pumps have also helped to improve the working conditions on the farms. The farms are now able to maintain a comfortable temperature throughout the year, which has led to increased productivity and reduced sick leave among employees.

In Germany, dairy company Müller has installed SHC heat pumps at its processing plant in Nördlingen. The plant produces a variety of dairy products, including milk, cheese, and yogurt. The heat pumps are used to cool the milk storage tanks, heat the water used in the production process, and provide air conditioning for the processing plant. The heat pumps have reduced the plant's energy consumption by 30 %, which has led to significant cost savings and reduced emissions. In New Zealand, dairy company Fonterra has installed a 2 MW SHC heat pump at one of its dairy farms. The system is expected to save the farm around \$100,000 per year in energy costs. The heat pump uses waste heat from the farm's milking parlor to heat the water used in the milking process. The heat pump also provides space heating and cooling for the farm's offices and staff accommodation. In Ireland, dairy company Glanbia has installed SHC heat pumps at several of its dairy farms. The company has found that the heat pumps have reduced their en-

ergy consumption by up to 30 %. The farms are also able to utilize waste heat from the farms' operations. In the United States, dairy company Dean Foods has installed SHC heat pumps at several of its processing plants. The company has found that the heat pumps have reduced their energy consumption by up to 20 %. The plants are also able to utilize waste heat from the plant's operations.

## Conclusions

This contribution aimed to show how integrating heat pumps enables the efficient utilization of waste heat from refrigeration systems to fulfill heating requirements, establishing a synergistic relationship between the two processes. Specifically, SHC heat pump technology is investigated to improve the energy and environmental performance of dairy companies leading to a zero-carbon industry, and real use cases through the discussion of pilot projects have been presented. These examples demonstrate that SHC heat pumps are a viable and effective technology for reducing energy consumption and environmental impact in the dairy sector. As the technology continues to develop and become more affordable, we can expect to see even more SHC heat pumps being installed in dairy operations around the world.

Integrating renewable energy sources for zero-carbon dairy with SHC heat pumps is a promising approach to reducing the environmental footprint of dairy production. This combination of technologies can significantly reduce energy consumption, lower greenhouse gas emissions, and promote sustainable dairy practices. The main benefits of integrating RES and SHC Heat Pumps in dairy operations are:

- **Reduced Energy Consumption:** RES can provide clean and renewable energy for powering various dairy operations, including milking machines, refrigeration systems, and lighting. SHC heat pumps can further enhance energy efficiency by providing both heating and cooling using a single system, reducing the need for separate heating and cooling units.
- **Lower Greenhouse Gas Emissions:** by transitioning away from fossil fuels and relying on RES, dairy operations can significantly reduce their greenhouse gas emissions, contributing to a more sustainable food system. SHC heat pumps can further reduce emissions by utilizing waste heat from various processes, improving the overall energy balance.
- **Improved Indoor Climate Control:** SHC heat pumps can provide precise temperature control in dairy barns, ensuring a comfortable environment for cows and improving their productivity. This can also enhance working conditions for employees and reduce sick leave.
- **Sustainable Dairy Practices:** the integration of RES and SHC heat pumps aligns with the dairy industry's commitment to sustainability and promotes resource conservation and environmental protection.

The next step of this study will consist of the quantitative assessment of that technology in a real case. A further extension

will consist of the assessment also of non-energy benefits which can further improve the feasibility of the technology (Neusel et al., 2020). In this optic, the LIFE-BETTED project took place, which aims to facilitate companies (especially small and medium, SMEs) belonging to dairy supply chains to foster the market uptake of energy efficiency measures including the use of renewables and the deployment of heat pumps at the value chain level.

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