



# Decarbonization of the Cheese Making Industry on the Island of Crete, Greece

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**ABSTRACT:** Cheese making is a well-developed activity in the island of Crete, Greece since a long time ago. It is mainly based on local sheep' and goats' milk while the small-scale cheese making plants in Crete use conventional energy sources to meet their heat and electricity demand. However, solar energy and solid biomass are abundant in the island and they are currently used for heat and power generation. Elimination of carbon emissions in cheese making plants in Crete can be achieved with the replacement of grid electricity and fossil fuels used with local renewable energies such as solar energy and solid biomass. It has been estimated that complete elimination of the operational carbon emissions due to energy use in a small-size cheese making plant in Crete with annual capacity 120 tons cheese can be achieved with the installation of a solar photovoltaic system at 88 kW<sub>p</sub> for electricity generation and the annual use of 62.86 tons of olive kernel wood for heat production. Additionally, solar thermal systems and high efficiency heat pumps can be used for heat and cooling production. The abovementioned sustainable energy sources and technologies are mature, reliable, cost-efficient and they are currently used in Crete in various sectors. The results of the present study could be useful to all stakeholders of the cheese making industry in the island.

**KEYWORDS:** carbon emissions, cheese, Crete-Greece, energy, industry, net-zero

## 1. INTRODUCTION

The elimination of carbon emissions in the industrial sector is prerequisite for achieving net-zero carbon societies in the coming decades. The food industry, including the cheese making industry, is responsible for a significant share in global greenhouse gas (GHG) emissions [1], [2], [3], [4], [5]. Cattle breeding and milk production have a share at around 70-90% in the life cycle emissions of cheese making industry [6], [7], [8]. Cheese making requires significant amounts of heat and electricity which traditionally are provided by fossil fuels [9], [10], [11]. However, several renewable energy sources can be used for heat and electricity generation in cheese making industry reducing or completely eliminating its carbon emissions due to energy use [12], [13]. The island of Crete has a long tradition in cheese making while its cheese industry is characterized by a large number of small to medium-sized dairies, many of which are family-owned and regionally focused [14], [15].

*The aim of the current research is to study the elimination of the operational net-carbon emissions due to energy use in cheese making industry in the island of Crete, Greece.*

The work is structured as follows: After the literature survey the cheese making process and the cheese production in Crete, Greece are stated. In the following two sections the energy consumption in cheese making plants and the decarbonization in food industry are analyzed. Next, the zeroing of the net-carbon emissions in cheese making plants in Crete is mentioning while the text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The text is innovative since there not similar studies published so far for the cheese making industry in Crete while it covers the existing gap regarding the decarbonization in cheese making plants in the island. The results could be useful to policy makers, to local authorities, to cheese making industry in Crete and to energy companies which provide and install benign energy systems.

## 2. LITERATURE SURVEY

The energy footprint of cheese has been reviewed [1]. The authors stated that there are over 500 cheese types globally, while their environmental impacts are related with the energy consumption the GHG emissions and the use of RES in cheese production. They mentioned that their energy consumption varies in the range of 3 MJ/kg to 70.2 MJ/kg while their GHG emissions in the range of 7.3 kgCO<sub>2e</sub> to 22.13 kgCO<sub>2e</sub> per kg of cheese. The carbon footprint (CF) of dairy milk and Grana Padano PDO cheese in the Po Valley, Italy has been assessed [2]. The authors stated that the CF of the cheese during its life cycle varies in the range of 16.96 kgCO<sub>2e</sub>/kg to 23.07 kgCO<sub>2e</sub>/kg. The life cycle of the Italian Mozzarella cheese has been assessed [3]. The authors estimated the life



cycle (cradle to grave) energy consumption at 45.1 MJ/kg and the carbon emissions at 6.66 kgCO<sub>2</sub>e/kg. The energy consumption in dairy supply chain has been modelled [4]. The authors stated that the average total CO<sub>2</sub> emissions in milk's production industry was for electricity at around 7 gCO<sub>2</sub>/l while for diesel at 20-55 gCO<sub>2</sub>/l depending on the route. The total electricity consumption was in the range of 34-43 kJ/l of milk while the diesel usage was in the range of 6.5 g/l to 17 g/l of milk depending on the route. The milk and cheese carbon footprints in two different systems in northern Spain have been compared [5]. The authors stated that the CF in the two systems were at 14.7 kgCO<sub>2</sub>e and 16.6 kgCO<sub>2</sub>e per kg of cheese. They mentioned that the production of milk represented more than 60% of CO<sub>2</sub> emissions associated with cheese production. The decarbonization of the supply chain in dairy industry has been explored [6]. The authors stated that dairy farms are producers of significant GHG emissions. They mentioned that animal-related activities and feed production in farms represent key areas for reducing carbon emissions. The energy management for achieving net-zero dairy supply chain has been studied [7]. The authors stated that the energy demand in dairy farms was at 2.7 MJ/kg of milk and in cheese manufacturing plants at 3.3 MJ/kg. They mentioned that it is difficult to decarbonize the cattle'-breeding sector. They proposed that the dairy industry should move efficiently towards net-zero carbon via collaboration among all stakeholders in the dairy supply chain. A report regarding the GHG emissions from the dairy sector through life cycle analysis (LCA) has been published [8]. It is stated that the GHG emissions from cheese processing, transport and packaging is at 0.126 kgCO<sub>2</sub>e per kg of milk at the farm's gate. The report mentioned that the total contribution of milk production, processing and transportation to global anthropogenic emissions are estimated at 2.7 % while the average emissions from milk production, processing and transport is 2.2 kgCO<sub>2</sub>e per kg of milk at farm's gate. The energy consumption during manufacturing certain dairy products on a small scale has been estimated [9]. The authors stated that the energy consumption of five types of cheese was in the range of 1.32 MJ/kg to 10.33 MJ/kg. They mentioned that the share of heat consumption in the total energy mix was varying in the range of 0.73% to 99.46%. The determinants of energy consumption in the dairy industry focusing in Poland have been examined [10]. The authors stated that the energy consumption was strongly correlated with the use of equipment while plants producing milk powder had higher energy consumption. They mentioned that the most energy consuming stage was milk pasteurization. The energy sustainability in the ripening of traditional cheese has been studied [11]. The authors stated that cheese ripening is an energy intensive process that requires precise control of temperature and humidity. They proposed the use of a solar-PV system generating the required electricity in the ripening stage. The use of renewable energies in cheese ripening chambers has been examined [12]. The authors described a sustainable energy system appropriate for artisanal and semi-industrial cheese making plants. They examined the use of solar-PV panels, wind turbines, solar thermal collectors, biomass boilers and thermal energy storage via phase change materials which allow the ripening chamber to achieve energy self-sufficiency at around 95%. The use of hydrogen for decarbonizing the dairy industry has been studied [13]. The authors investigated the integration of on-site green H<sub>2</sub> produced by solar-PV systems as substitute of CH<sub>4</sub> in steam generation during the production of Parmigiano Reggiano Cheese. The authors stated that according to several scenarios examined the investment was not profitable. The production of Xugalo cheese in Siteia, Crete, Greece has been explored [14]. The authors stated that during its production the milk was pasteurized at 71.8°C for 18 sec or at 65°C for 30 minutes. The characteristics of cheese making technology of several Greek cheeses have been explored [15]. The authors mentioned the famous cheese Graviera that holds the second share after feta in the Greek market while the Cretan graviera is registered as protected designation of origin. The environmental impacts of cheese production in a small-scale factory in southern Spain have been investigated [16]. The authors estimated the LCA carbon footprint at 10.2 kgCO<sub>2</sub>e/kg of cheese. They mentioned that the fat and dry extract of several cheeses affect their carbon footprint. The carbon neutrality in cheese making has been studied [17]. It is stated that more than 90% of the emissions in the life cycle of cheese are originated from milk production. It is also mentioned that in cheese making plants both electricity and heat are used. Additionally, these plants can invest in carbon reduction projects offsetting their carbon emissions. An environmental assessment in a cheese production plant examining its sustainable energy transition has been conducted [18]. The authors studied the replacement of 33% of the natural gas used with biomass and with geothermal energy. They mentioned that the use of geothermal energy had better environmental impacts than the use of biomass. The navigation path to net-zero in dairy companies has been reported [19]. It is stated that the thirty largest dairy companies have set targets for reducing their CO<sub>2</sub> emissions by 38% in 2030 compared to 2020. It is also mentioned that the CO<sub>2</sub> emissions involved in milk production vary significantly by region due to several factors. The energy use and performance of global cheese processing have been examined [20]. The authors stated that the energy consumption in cheese making plants varies significantly in the range of 1.8 MJ/kg to 68.2 MJ/kg of cheese. The sustainable approach in the production of Izmir Tulum cheese following a LCA from



raw milk production to cheese processing has been examined [21]. The authors estimated that the full transition to solar-PV electricity can reduce the global warming potential (GWP) by 54.5% while by meeting the heat energy demand by solar thermal energy reduces the GWP by 9.1%. A report related to net-zero food production has been published [22]. The report stated that the food sector is responsible for up to one third of global GHG emissions. It is mentioned that only a minority of food producers have reported sufficient data to enable the assessment of historical emissions intensities. A net-zero road map for sustainable dairy manufacturing has been presented [23]. The authors evaluated the embodied energy of the skimmed milk product in the range between 309 kJ/l and 869 kJ/l while its carbon footprint between 7.6 gCO<sub>2e</sub> and 59.1 gCO<sub>2e</sub> per l. They mentioned that the most energy intensive processes are transportation, cleaning in place and heat treatment. The circular economy principles in the cheese production chain in Laticinos Alto Uruguai have been investigated [24]. The authors stated that from a life cycle perspective the highest food losses and wastes occur in post-harvest handling and storage (34.49%) and at the consumption stage (48.12%). A report regarding the future for dairy companies on the path to net-zero has been published [25]. It is stated that most emissions, approximately at 80-85%, in the life cycle of dairy products arise at the beginning of the value chain. It is also mentioned that the carbon emissions related to milk production is different in several countries and regions varying in the range of 0.74 kgCO<sub>2e</sub> to 1.73 kgCO<sub>2e</sub> per kg of milk. The report stated that solar-PV systems can be used for power generation while heat pumps, biomass boilers, solar thermal systems and hydrogen can be used for heat production. The energy cost of parmesan cheese has been estimated [26]. The authors stated that about 64 kWh of electrical energy and 94 kWh of thermal energy are used in the production of a parmesan cheese wheel while 174 kWh are required in the production of milk. The electric energy consumption in a dairy cooperative producing milk, cheese, butter and yogurt has been evaluated [27]. The authors stated that the highest electricity consumption was in the cooling phase while the lowest in the cleaning the place. The main traditional cheeses made in Mediterranean basin have been reviewed [28]. The authors stated that Mediterranean cheeses have a rich heritage shaped by centuries of tradition reflecting their strong cultural values and the importance of preserving them. The compositional differences in Greek cheeses of limited production have been explored [29]. The authors stated that Greece has a long tradition in cheese making with 22 cheeses registered as protected designation origin. They mentioned that differences in cheese originate from the differences in milk composition between cows, sheep and goats and from different manufacturing procedures and ripening. The energy efficiency in Portuguese traditional Cheese making industries has been examined [30]. The authors studied several traditional industrial and handmade cheese producers stating that around 58% of the energy was used in the cooling systems. They mentioned that the energy consumption in cheese making plants varied in the range of 0.169 kWh to 0.283 kWh per liter of milk. The use of green energy technologies in dairy industry to reduce the carbon footprint has been studied [31]. The authors stated that the adoption of green sustainable, energy efficient and eco-friendly technologies in dairy industry can reduce its adverse environmental impacts. The development of carbon neutral olive oil mills due to energy use in Crete, Greece has been studied [32]. The author stated that an olive oil mill in Crete producing 200 tons of olive oil per year can eliminate all its operating net-carbon emissions with the installation of a solar-PV system with nominal capacity 13.33 kW<sub>p</sub> meeting its annual electricity demand and consuming 9,524 kg of olive kernel wood per year for heat production meeting its annual heat demand. The deployment of carbon neutral olive pomace plants in Crete, Greece has been explored [33]. The author stated that 99.1% of the energy consumption in these plants is used for heating and steam production while the remaining 0.9% for electric uses. He mentioned that part of the olive kernel wood produced in these plants is used for their own heat generation while the required electricity can be generated from locally installed solar-PV panels. Table 1 indicates the energy consumption in cheese making plants while Table 2 the carbon emissions in these plants.

**Table 1. Energy consumption in cheese making plants**

Author/year	Energy consumption (MJ/kg of cheese)	Comments
Silverio et al, 2025	3.0 - 70.2	Data from several countries
Xu et al, 2009	1.8 - 68.2	Several countries and regions
Shenana et al, 2002	1.32 – 10.33	Several types of cheese
Malliaroudaki et al, 2022	3.3	Energy analysis in the whole supply chain has been made
Dala Rive et al, 2017	45.1	Italian Mozzarella cheese
Nunes et al, 2025	6.08-10.20	Portuguese cheese, assuming that production of 1 kg of cheese requires 10 liters of milk

Source: several authors



**Table 2. Carbon emissions in cheese making plants**

Author/year	Carbon emissions (kgCO <sub>2</sub> eq/kg of cheese)	Comments
Canellada et al, 2018	10.2	Small-scale plant in South Spain
GHG emissions from the dairy sector, 2010	1.26	Includes transportation and packaging
Dala Rive et al, 2017	6.66	Italian Mozzarella cheese
Ferronato et al, 2025	16.96 – 23.07	Italian cheese
Silverio et al, 2025	7.3- 22.13	Data from several countries
Laca et al, 2019	14.7-16.6	Small-scale plant in north Spain

Source: several authors

### 3. THE CHEESE MAKING PROCESS

Cheese making is a traditional yet scientifically intricate process that transforms milk into a wide variety of flavorful and textured products. This process, developed thousands of years ago, combines biological, chemical, and physical changes to produce cheeses that differ in taste, consistency, and appearance depending on the methods used. The process begins with milk, typically sourced from cows, goats, or sheep. The quality and composition of the milk play a crucial role in determining the final product. Fresh milk is first standardized and often pasteurized to eliminate harmful microorganisms while preserving its nutritional properties. Pasteurization involves heating the milk to a specific temperature for a set period, ensuring safety without significantly altering flavor. It can be achieved at 71.7°C for 15 sec or in lower temperature for more time. Once prepared, the milk is cooled to an optimal temperature, and starter cultures are added. These cultures consist of beneficial bacteria that ferment lactose, the natural sugar in milk, into lactic acid. This acidification process is essential, as it influences both the flavor and texture of the cheese. It also helps in coagulating the milk proteins, preparing them for the next step. The addition of rennet marks a key stage in cheese making. Rennet is an enzyme, traditionally derived from the stomach lining of young ruminants, although microbial and plant-based alternatives are now widely used. When added to the milk, rennet causes the casein proteins to coagulate, forming a gel-like structure known as curd. This separates from the liquid portion called whey. The formation of curds is a defining moment in cheese production, as it transforms liquid milk into a semi-solid mass. After coagulation, the curd is cut into smaller pieces to facilitate the release of whey. The size of the curd pieces affects the final cheese: smaller curds lead to harder cheeses, while larger curds retain more moisture and produce softer varieties. The curds are then gently heated and stirred, a process known as cooking, which further expels whey and firms up the texture. Once the desired consistency is achieved, the whey is drained, and the curds are collected. At this stage, the curds may be salted to enhance flavor, control microbial activity, and improve preservation. In some cheese varieties, additional steps such as cheddaring—where curds are stacked and turned—are applied to develop specific textures and flavors. The curds are then shaped and pressed into molds to form the cheese. Pressing removes any remaining whey and helps the cheese achieve its final structure. The pressure applied and duration of pressing vary depending on the type of cheese being produced. The final stage of cheese making is aging, also known as ripening. During this period, which can last from a few days to several years, biochemical processes continue to develop the cheese’s flavor, aroma, and texture. Enzymes and microorganisms break down proteins and fats, creating complex compounds that give each cheese its unique characteristics. Environmental conditions such as temperature and humidity are carefully controlled to ensure proper maturation. Therefore, cheese making is a multifaceted process that blends tradition with science. From milk preparation to aging, each step plays a vital role in shaping the final product. The diversity of cheeses available today reflects the variations in techniques, ingredients, and conditions used throughout this fascinating process.

### 4. CHEESE PRODUCTION IN CRETE, GREECE

The cheese-making industry in Crete is notable not only for its long tradition but also for its distinctive structure in terms of size and number of production units. Unlike highly industrialized dairy sectors found in other parts of Europe, Crete’s cheese industry is characterized by a large number of small to medium-sized dairies, many of which are family-owned and regionally focused. Although precise official figures vary depending on classification, available evidence suggests that the island hosts dozens to potentially over a hundred organized dairies, alongside numerous small artisanal producers. In specific regions such as Siteia in eastern Crete, there are “a few decades” (i.e., several dozen) small-scale producers operating alongside a handful of larger factories,



highlighting the fragmented and localized nature of the industry. These small units often supply local markets, taverns, and tourism-related businesses, rather than engaging in large-scale export. The size of cheese-making enterprises in Crete is generally modest. Most dairies process limited quantities of milk compared to industrial producers in mainland Europe. Production is typically based on sheep and goat milk collected from nearby farms, and facilities often operate at a regional level rather than nationwide. Even where modern technology is used, the scale remains relatively small, preserving traditional production methods and product identity. A key feature of the Cretan dairy sector is that many businesses are family-run, reflecting the island’s agricultural heritage. These enterprises often employ only a small workforce and maintain close relationships with local livestock farmers. This decentralized structure contributes to the diversity of cheeses produced—over 14 different types are made on the island—while also limiting large-scale consolidation. In recent decades, however, there has been a gradual shift toward larger, certified dairy units that meet European Union standards. These modern facilities coexist with traditional producers, creating a dual system: on one hand, small artisanal units rooted in local culture; on the other, medium-sized enterprises capable of standardized production and export. Despite this modernization, the overall industry in Crete remains relatively small in scale compared to national or international dairy industries. Therefore, the cheese-making industry in Crete is defined by its high number of small producers and relatively limited industrial scale. Rather than being dominated by a few large corporations, it consists of a network of local dairies that balance tradition with gradual modernization. This structure not only preserves the island’s cultural identity but also ensures the continued diversity and quality of its cheese production. Table 3 indicates the quantity of cheese produced in Crete and in Greece.

Table 3. Quantity of cheese produced in Crete and in Greece (2023)

Type of Cheese	Crete (tons)	Greece (tons)	Crete/Greece (%)
Soft	3,287	202,845	1.62
Hard	6,466	27,026	23.93
Mizithra	2,269	12,074	18.79
Cream	32	6,580	0.49
Total	12,054	248,525	4.85

Source: [34]

### 5. ENERGY CONSUMPTION IN CHEESE MAKING PLANTS

The cheese-making industry is an important segment of the global food system, but it is also energy-intensive and associated with significant GHG emissions. As demand for dairy products continues to grow worldwide, understanding the environmental footprint of cheese production—particularly energy consumption and emissions—has become increasingly important for sustainability efforts. Energy consumption in the cheese-making industry occurs at multiple stages, from milk production to processing, storage, and distribution. The first major energy input lies in dairy farming, where electricity and fuel are used for milking machines, refrigeration, feed production, and transportation. However, within cheese manufacturing itself, energy is primarily consumed in heating, cooling, and mechanical operations. For example, pasteurization requires substantial thermal energy to heat milk to specific temperatures to eliminate harmful microorganisms. Similarly, curd processing, whey separation, and cleaning operations rely on both thermal and electrical energy. Cooling is another critical energy demand in cheese production. After processing, cheese must be stored under controlled temperature and humidity conditions, sometimes for extended aging periods. This is particularly true for hard and specialty cheeses, which may require months or even years of maturation. Refrigeration systems, therefore, contribute significantly to overall energy consumption. In addition, modern cheese plants use automated equipment, pumps, and compressors, all of which require electricity and further increase energy use. The sources of this energy greatly influence the environmental impact of cheese production. Facilities that rely on fossil fuels such as natural gas or oil for heat generation produce higher GHG emissions compared to those using renewable energy sources. Electricity consumption also contributes indirectly to emissions, depending on the energy mix of the region. In countries where coal or gas dominates electricity generation, the carbon footprint of cheese production is notably higher. Greenhouse gas emissions in the cheese-making industry are not limited to energy use alone. A substantial portion originates upstream, particularly from dairy farming. Methane emissions from enteric fermentation in cows represent one of the largest contributors. Additionally, manure management releases both methane and nitrous oxide (N<sub>2</sub>O), another potent greenhouse gas. Feed production, including the use of fertilizers and land-use changes, further adds to emissions. When



considering the full life cycle, cheese tends to have a higher carbon footprint compared to other dairy products because it requires large volumes of milk—approximately 10 liters of milk to produce 1 kilogram of cheese. Within processing plants, emissions also arise from wastewater treatment and by-product management. Whey, a liquid by-product of cheese-making, can generate emissions if not properly utilized or treated. However, many facilities have begun to valorize whey by converting it into protein powders or using it for energy generation, thus reducing waste and emissions. Efforts to reduce energy consumption and GHG emissions in the cheese industry are gaining momentum. Energy efficiency measures, such as heat recovery systems, improved insulation, and optimized processing techniques, can significantly lower energy demand. The adoption of renewable energy sources, including solar panels and biogas systems derived from organic waste, is also becoming more common. On the farming side, improved animal diets, manure management practices, and breeding strategies can help reduce methane emissions. Therefore, the cheese-making industry is associated with considerable energy use and greenhouse gas emissions across its value chain. While processing activities contribute to energy demand, the majority of emissions originate from milk production. Addressing these challenges requires a holistic approach that includes technological innovation, energy efficiency, and sustainable agricultural practices. By implementing such measures, the industry can move toward reducing its environmental impact while continuing to meet global demand of cheese. Table 4 indicates the energy demand in several stages of cheese making.

**Table 4. Energy demand in several stages of cheese making (kWh/lit of milk)**

Stage	Power demand	Heat demand	Total energy demand	Temperature
Milk collection and storage	0.02-0.05	-	0.02-0.05	2-4°C
Pasteurization	0.01-0.02	0.2-0.3	0.21-0.32	72-75°C
Addition of starter culture and coagulation	0.005-0.01	0.02	0.025-0.03	Low
Cutting and cooking the curd	0.01	0.05-0.1	0.06-0.11	38-42°C
Whey drainage and molding	0.005	-	0.005	
Pressing	0.01-0.02	-	0.01-0.02	
Salting	0.002-0.005	-	0.002-0.005	
Ripening	0.05-0.15	-	0.05-0.15	8-15°C
Total	0.1-0.3	0.3-0.5	0.4-0.8	

Source: various authors

## 6. DECARBONIZATION IN FOOD INDUSTRY

Decarbonization in the food processing industry has become a critical priority as governments, companies, and consumers push toward reducing greenhouse gas emissions. Food production is energy-intensive, involving processes such as heating, cooling, drying, and packaging, all of which traditionally rely on fossil fuels. To achieve meaningful emissions reductions, the industry must address two key dimensions of energy use: heat and electricity. While both are essential, they present distinct challenges and require different decarbonization strategies. Electricity decarbonization is generally more advanced and straightforward. It involves replacing fossil fuel-based power generation with renewable energy sources such as wind, solar, and hydropower. Food manufacturers can decarbonize electricity consumption by purchasing green energy through utility providers, entering power purchase agreements, or installing on-site renewable systems like solar-PV panels. Because electricity is already a flexible and widely distributed energy carrier, transitioning to clean electricity often requires minimal changes to existing equipment. For example, refrigeration systems, conveyors, and automated packaging lines can operate on renewable electricity without significant redesign. As a result, many companies have made rapid progress in reducing emissions associated with electricity use. In contrast, heat decarbonization is more complex and represents a larger share of energy consumption in many food processing operations. Heat is required for processes such as baking, pasteurization, sterilization, drying, and cooking. These processes often demand high temperatures and continuous, reliable energy supply, which has historically been provided by burning natural gas or other fossil fuels on-site. Unlike electricity, heat is not easily transported over long distances, and renewable alternatives require substantial changes to infrastructure. Several pathways exist for decarbonizing heat, but each comes with trade-offs. Electrification of heat in low-temperature applications — using technologies like electric boilers or heat pumps—is one option, especially for low- to medium-temperature processes. Another approach is the use of renewable fuels such as biogas, biomass, or green hydrogen. These



can often be integrated into existing systems, but their availability, cost, and sustainability vary significantly. Additionally, improving energy efficiency—through better insulation, heat recovery systems, and process optimization—plays a crucial role in reducing overall heat demand. The distinction between heat and electricity decarbonization highlights a broader challenge: while clean electricity solutions are increasingly accessible and scalable, heat decarbonization in several cases requires deeper technological innovation and capital investment. Food manufacturers must therefore adopt a dual strategy—rapidly transitioning to renewable electricity while simultaneously investing in long-term solutions for sustainable heat. Ultimately, achieving full decarbonization in the food manufacturing sector will depend on coordinated efforts across technology development, policy support, and supply chain transformation. By addressing both electricity and heat, the industry can significantly reduce its environmental impact while ensuring the continued production of safe, affordable, and high-quality food. Apart from renewable energies use, carbon offsetting in the food processing industry has become an important strategy for reducing environmental impacts. As food production generates significant greenhouse gas emissions through energy use, transportation, and packaging, companies are increasingly investing in offset projects such as reforestation, renewable energy production, and sustainable agriculture. While offsetting helps balance emissions, it should not replace direct efforts to improve efficiency and reduce carbon emissions within the food processing plants. An effective approach should combine emission reduction at the plant with transparent and credible offsetting initiatives.

**7. ZEROING THE NET-CARBON EMISSIONS IN CHEESE MAKING INDUSTRY IN CRETE, GREECE**

The possibility of zeroing the net-carbon emissions during the operation in a small-scale cheese making plant is examined. The following assumptions are made:

- a) The capacity of the plant is 120 tons cheese annually while the ratio of heat to electricity use is 2/1.
- b) The electricity demand will be met by a grid-connected solar-PV system while the heat demand by a biomass boiler using solid biomass. The biomass boiler will produce hot water and steam required in the plant.
- c) The solar-PV system generates annually 1,500 kWh per 1 kW<sub>p</sub> in Crete.
- d) The solid biomass has a heating value at 4.2 kWh/kg. Olive kernel wood which is a by-product of the local olive oil industry can be used.
- e) The total energy consumption is assumed at 12 MJ/kg (3.33 kWh/kg) of cheese. The heat consumption is 8 MJ/kg (2.22 kWh/kg) while the electricity consumption 4 MJ/kg (1.11 kWh/kg).

The annual electricity consumption in the cheese making plant is 120,000 tons/year X 1.11 kWh/kg = 132,000 kWh/year. The nominal power of the required solar-PV system is 132,000 (kWh/year)/1,500 (kWh/kW<sub>p</sub> year) = 88 kW<sub>p</sub>.

The annual heat consumption in the plant is 120,000 kg/year X 2.22 kWh/kg = 264,000 kWh/year.

The required quantity of solid biomass is 264,000 (kWh/year)/4.2 (kWh/kg) = 62.86 tons/year.

It should be noted that solar-PV systems and solid biomass burning are broadly used in Crete nowadays for power and heat generation. Table 5 indicates the characteristics of a small-scale cheese making plant in Crete with net-zero carbon emissions during its operation while table 6 the zero carbon energy technologies that can be used in cheese making plants in Crete.

**Table 5. Characteristics of a small-scale cheese making plant in Crete with net-zero carbon emissions during its operation**

Parameter	Value
Plant capacity	120 tons cheese per year
Total energy consumption	3.33 kWh/kg of cheese
Electricity consumption	1.11 kWh/kg
Heat consumption	2.22 kWh/kg
Annual electricity consumption	132,000 kWh
Annual heat consumption	264,000 kWh
Annual electricity consumption from a solar-PV system in Crete	1,500 kWh/kW <sub>p</sub>
Heat capacity of solid biomass	4.2 kWh/kg
Nominal capacity of the solar-PV system	88 kW <sub>p</sub>
Required quantity of solid biomass	62.86 tons/year

Source: own estimations



**Table 6. Zero carbon energy technologies that can be used in cheese making plants in Crete**

Energy source	Technology	Energy produced	Current applications in Crete
Solar energy	Solar photovoltaic panels	Electricity	Yes
Solar energy	Solar thermal mirrors	Heat	Yes
Solid biomass	Burning	Heat	Yes
Green electricity and ambient heat	High efficiency heat pumps	Heat and cooling	Yes
Solar energy	Absorption cooling system	Cooling	No
Solar energy	Parabolic trough collector	Heat/electricity	No
Biogas produced by cheese making wastes	Burning	Heat and electricity	No
Solar energy and biomass	Hybrid system with solar mirrors and biomass burning	Heat	No
Electricity	Electric batteries	Electricity	Yes
Heat	Phase change materials/storage tanks	Heat	Yes

Source: own estimations

## 8. DISCUSSION

The elimination of the operational carbon emissions due to energy use (scope-1 and scope-2 emissions excluding transportation) in the cheese making industry in Crete, Greece has been examined. Crete has a long tradition in cheese making producing different types of cheese while its industry is dominated by small-scale and artisanal family-owned facilities. These facilities utilize mainly milk produced locally from sheep and goats instead of cows' milk. Energy consumption and carbon emissions depend on the size of the cheese making plants while often heat requirements are higher than power demand. Their values vary significantly depending on the country, the region, the type of cheese, the size of the cheese making plant as well as the machinery and the energy sources used. Unfortunately, we did not find published data regarding the energy consumption and carbon emissions in cheese making plants in Crete. It has been indicated that using solar-PV systems for power generation and locally produced solid biomass for heat production all the energy demand in cheese making plants in Crete can be met. Several studies have indicated that carbon emissions in the initial stages of cheese making chain, such as cattle breeding and milk production, are significantly higher than emissions in cheese making plants. Apart from using locally available solid biomass for heat production cheese making plants can utilize solar thermal energy, high efficiency heat pumps and hybrid systems using solar thermal energy and solid biomass. Taking into account the small size of cheese making plants in Crete processing of cheese whey for biogas production is not profitable. Our study did not estimate the installation and operational cost of the proposed renewable energy systems as well as their profitability. It did not also mention the existing barriers which hinder the decarbonization of these plants. Future work should examine different options of renewable energy systems that can be used in cheese making plants in Crete estimating their cost and profitability. It should also present the advantages and drawbacks regarding the use of benign energy systems in the cheese making industry in the island.

## 9. CONCLUSIONS

The elimination of the operational net-carbon emissions due to energy use in cheese making industry in the island of Crete, Greece has been examined. Data from existing studies worldwide regarding the energy consumption and carbon emissions in cheese making plants in several countries and regions have been used. The main findings of the current study include:

- The total cheese production in Crete is 12,054 tons in 2023 corresponding at 4.85% in Greece' cheese production,
- The average energy consumption in cheese making industry varies significantly in the range of 1.8 to 70.2 MJ per kg of cheese,
- The average carbon emissions in cheese making industry varies in the range of 1.26 to 23.7 kgCO<sub>2e</sub> per kg of cheese. The carbon emissions related to cattle breeding, milk production and transport are significantly higher than the emissions in cheese making plants,



- d) Several renewable energy sources and technologies can be used for heat and power generation in cheese making plants in Crete. These include: solar-PV systems, solar thermal systems, solid biomass heating systems, high efficiency heat pumps and hybrid energy systems,
- e) A small-scale cheese making plant in Crete producing 120 tons of cheese annually can meet all its power requirements using a solar-PV system with nominal capacity 88 kW<sub>p</sub> and all its heat demand using 62.86 tons/year olive kernel wood,
- f) Alternatively, solar thermal energy and high efficiency heat pumps can be used in these plants for heat and cooling production,
- g) The abovementioned sustainable energies and technologies are broadly used to day for heat and power generation in several sectors in Crete, and
- h) The energy technologies that could eliminate all the operational carbon emissions due to energy use in cheese making plants in Crete, Greece are mature, reliable and cost-efficient.

Therefore, decarbonization of cheese making plants in Crete is technically feasible using mature, reliable and cost-efficient renewable energy technologies.

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