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Possibilities of Decarbonizing Food Processing Industries in the Island of Crete, Greece

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ABSTRACT: Industrial decarbonization is necessary for climate change mitigation. Although elimination of carbon emissions in few industrial sectors is rather difficult food industries can easily eliminate their carbon footprint. The decarbonization of various food industries including olive mills, wineries and cheese making plants in Crete, Greece has been examined. These industries use mainly conventional energy sources and fuels for heat and power generation. Data from existing literature regarding the energy consumption and carbon emissions in similar plants have been used. Several renewable and clean energy technologies including solar photovoltaic, solar thermal, biomass burning and heat pumps can be used in these industries meeting their operational power, heat and cooling demand. Solar energy and solid biomass resources are abundant in Crete while they are currently used in the island for heat and power generation. The carbon emissions per unit of product in olive mills is lower than the corresponding emissions in wineries and cheese making plants. Therefore, decarbonization of olive mills, wineries and cheese making plants in Crete can be easily achieved using various mature, reliable and cost-efficient sustainable energy technologies. The results can be used by policy makers, local authorities and the owners of olive mills, wineries and cheese making plants in Crete.

KEYWORDS: carbon emissions, cheese, Crete-Greece, industries, olive oil, renewable energy technologies, wine

1. INTRODUCTION

Manufacturing industries contribute more than one third of global carbon emissions (1), (2). Their decarbonization is necessary for achieving the climate mitigation targets by 2050. Industrial decarbonization can be achieved with the combination of energy saving, use of low- and zero-carbon fuels and energy sources, carbon capture and offsetting carbon emissions (3), (4). The island of Crete, Greece hosts several food processing industries including olive oil mills, wineries and cheese making plants. They mainly use grid electricity and conventional fuels. The carbon footprint of wineries (5), (6), (7), olive mills (8), (9), (10), (11) and cheese making plants (12), (13), (14) in several countries has been estimated. The island has abundant solar energy and solid biomass resources which are currently used for heat and electricity generation.

The aims of the current study are: a) to examine the sustainable and low-carbon energy technologies which can be used in several food industries in the island of Crete, Greece including olive oil mills, cheese making plants and wineries promoting their decarbonization, and b) to compare the carbon emissions during olive oil, cheese and wine production in Crete.

The text is structured as follows: After the literature survey the industrial decarbonization is analyzed. In the next three sections the decarbonization of cheese making plants, wineries and olive oil mills are stated. In the following two sections the sustainable and low-carbon energy technologies which can be used in the abovementioned industries and comparison of their carbon emissions are mentioned. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The text is innovative since there are not many studies regarding the decarbonization of food industries in Crete while it covers the existing gap regarding decarbonization of cheese making plants, wineries and olive mills in Crete. The results could be useful to policy makers, local authorities and to stakeholders of the abovementioned industries in Crete.

2. LITERATURE SURVEY

A report on industrial decarbonization has been published (1). The report stated that manufacturing industries account for as much as 40% of global CO_2 emissions. It is also mentioned that most of the needed technologies are at demonstration phase or in early stages of commercialization and many of them are capital-intensive. The new frontiers in research on industrial decarbonization have been explored (2). The authors stated that although substantial advances towards global decarbonization have been made in several areas, decarbonization of energy-intensive industries remains a crucial challenge. They mentioned that with current technologies and policies industrial decarbonization appears technically possible but difficult and costly. The industrial decarbonization roadmap and context has been studied (3). The author stated that the four pillars of industrial decarbonizations are energy efficiency, industrial electrification, low-carbon fuels and energy sources and carbon capture, utilization and storage. He also mentioned that future efforts should be focused on pursuing industrial heat decarbonization and increasing capital investments in the expansion of renewable energies and low-carbon technologies. The industrial decarbonization has been studied (4). The authors stated that emission reduction that can be achieved through conventional means is limited. They mentioned that traditional energy efficiency and fuel substitution approaches cannot decarbonize several industrial sectors. The carbon footprint of a wine making company located in northern Greece has been estimated (5). The authors stated that vineyard emissions had a share at 32% in total emissions while emissions in the winery had a share at 68% in total emissions. They also mentioned that scope 3 emissions has a share at 54% in total emissions, scope 1 at 25% while scope 2 at 21%. The energy use and the carbon footprint of wine and wine grapes have been explored (6). The authors stated that electricity use is the dominant factor contributing to total carbon emissions. They also mentioned that the carbon footprint of 1 kg grapes is 0.012 $kgCO_{2e}$. The life-cycle carbon footprint of Greek organic red wines has been estimated (7). The authors stated that the carbon footprint of wines was estimated in the range of 0.69 to 1.14 $kgCO_{2e}$ per 0.75 l of wine. A zero-impact olive mill which produces energy has been reported in Italy (8). The olive mill’s wastes were anaerobically digested producing biogas which was used for heat and power cogeneration. The amount of the cogenerated electricity was exceeding the electricity demand in the olive mill. The energy efficiency in olive mills has been studied (9). The authors analyzing data from 123 Portuguese olive mills stated that they were using mainly electricity at 98.3% with low contribution of biomass, diesel and gas. They mentioned that the heat energy consumption was higher than the electrical energy consumption. Olive mills powered by renewable energy sources such as solar energy, wind energy and biomass in Andalusia, Spain have been studied (10). The authors stated that olive mills can use solar photovoltaics for power generation and biomass for heat production. The use of rooftop grid-connected solar-PV systems in olive mills has been explored (11). The authors stated that the renewable energy produced could cover between 11% and 84.7% of the mill’s energy consumption while the reduction of the carbon footprint could be between 22% and 119% depending on the system boundaries considered. A case study on 31 Portuguese cheese making plants has been conducted (12). The authors stated that electricity had a share at 58% in the total energy mix while conventional fuels were used in heat production. They also mentioned that industrial cheese producers were consuming more energy than traditional home-made cheese producers. The energy cost of parmesan cheese has been examined (13). The authors stated that about 64 kWh of electrical energy and 94 kWh of thermal energy are needed in the production of a parmesan cheese wheel. A critical review on energy footprint of cheese has been conducted (14). The authors stated that the energy consumption in cheese making varied significantly in the range of 3.0 to 70.2 MJ/kg depending on many factors while the GHG emissions were up to 22.13 $kgCO_{2e}$ per kg of cheese. The life-cycle carbon footprint in several grape varieties in Cyprus has been estimated (15). The authors studied 90 vineyards in Cyprus using a system boundary from the vineyard to the winery/market door. They stated that the variety Soultanina had the highest carbon footprint at 0.846 $kgCO_{2e}$ per kg of grapes while other varieties had lower carbon footprint at 0.556 $kgCO_{2e}$ per kg of grapes and 0.283 $kgCO_{2e}$ per kg of grapes. A benchmarking study regarding the carbon footprint in the Italian wine sector has been implemented (16). The authors studied the life cycle carbon emissions of 33 Italian wines from 16 wineries. They estimated that their carbon footprint varies in the range of 0.899 to 1.882 kg CO_{2e} per 0.75 l of wine. The carbon emissions in the Australian wine industry have been examined (17). The authors stated that the average footprint of Australian wines is in the range of 0.6 to 1.4 $kgCO_{2e}$ per l of wine with an average value at 1.2 $kgCO_{2e}$ per l of wine. They also explained that the carbon release during grapes’ fermentation is very low and it does not contribute to the wine’s industry carbon footprint. The energy efficiency in the olive oil producing industry has been examined (18). The authors stated that the energy consumption in the batch system was double than the continuous one. The net-zero roadmap for sustainable dairy manufacturing and distribution has been examined (19). The authors investigated 12 different scenarios testing a) three heating fuels – oil, natural gas and hydrogen, b) two categories of refrigeration vehicles – diesel and electric, and c) two distribution infrastructures – centralized and decentralized. They mentioned that carbon emissions reduction up to 90.2% can be achieved by 2050. The energy use and performance of global cheese processing have been investigated (20). The authors stated that the average energy intensity in cheese manufacturing in few countries varies in the range of 4.9 to 8.9 MJ per kg of cheese while the energy density in different countries in various plants varies in the range of 1.8 to 68.2 MJ per kg of cheese. The global footprint of cheese production in a small-scale factory in southern Europe has been estimated (21). The authors stated that the evaluated life-cycle global warming potential was at 10.2 $kgCO_{2e}$ per kg of cheese which is within the range reported for other cheeses at 8.6 to 16.2 $kgCO_{2e}$ per kg. The just and equitable industrial decarbonization has been studied (22). The authors stated that industrial decarbonization could provide a range of benefits to local communities from jobs creation and job security to investments and community growth. They mentioned that governmental funding opportunities are required to promote and implement industrial decarbonization applications and projects. The effectiveness of industrial decarbonization policies has been studied (23). The authors examined two policy types such as: a) payments, finance and taxation, and b) strategic plans. They mentioned that industrial decarbonization policy has persistent effects well into the future lasting between 4-18 years on average. They stated that one of the most difficult to decarbonize sectors in the global economy is the industrial sector. The carbon emissions due to wine making in the island of Crete, Greece have been evaluated (24). The author stated that the annual wine production in 2020 in Crete was 250,000 hl. Assuming that the average life-cycle carbon emissions in wine making are 1.6 $kgCO_{2e}$ per l of wine, he stated, that the annual carbon emissions due to wine making in the island are 40,000 $tnCO_{2e}$. The development of net-zero emission olive oil mills in the island of Crete, Greece has been examined (25). The author stated that an olive oil mill in Crete producing annually 200 ton of olive oil can eliminate all its operational carbon emissions with the installation of a solar-PV system with nominal capacity 13.33 kW_p and the use of 9,524 kg/year of olive kernel wood. The decarbonization of the cheese making industry in Crete has been studied (26). The author stated that elimination of the operational carbon emissions in a cheese making plant in Crete, Greece with annual capacity of 120 tons cheese can be achieved with the installation in the plant of a solar-PV system of 88 kW_p and the use of 62.86 tons of olive kernel wood for heat production.

3. INDUSTRIAL DECARBONIZATION

Decarbonization has become a major priority for industries worldwide as governments, businesses, and societies seek to combat climate change and reduce greenhouse gas emissions. Industrial sectors such as manufacturing, energy, transportation, and construction contribute significantly to global carbon emissions. To effectively achieve net-zero emission targets, industries must address emissions across Scope 1, Scope 2, and Scope 3 categories. Scope 1 emissions refer to direct emissions generated from industrial operations. These include fuel combustion in factories, emissions from company-owned vehicles, and industrial processes. Industries can reduce Scope 1 emissions by adopting cleaner technologies, improving energy efficiency, switching to renewable fuels, and electrifying industrial processes. Scope 2 emissions are indirect emissions resulting from purchased electricity, heating, or cooling consumed by a company. Although these emissions occur outside the company's facilities, they are associated with the organization's energy use. To decarbonize Scope 2 emissions, industries are increasingly investing in renewable energy sources such as solar, wind, and hydroelectric power. Many companies are also entering power purchase agreements (PPAs) to secure clean electricity supplies. Scope 3 emissions are often the largest and most challenging to manage because they arise from the entire value chain, including suppliers, transportation, product use, and waste disposal. These emissions are indirect but significantly impact the environment. Reducing Scope 3 emissions require collaboration among suppliers, customers, and stakeholders. Companies can encourage sustainable sourcing, optimize logistics, design low-carbon products, and promote recycling and circular economy practices. Industrial decarbonization requires a comprehensive strategy that addresses all three emission scopes. While Scope 1 and Scope 2 emissions can be controlled through operational improvements and renewable energy adoption, Scope 3 emissions demand broader cooperation across supply chains. Together, these efforts are essential for achieving global climate goals and ensuring a sustainable future.

4. DECARBONIZATION OF CHEESE-MAKING INDUSTRIES IN CRETE

The cheese-making industry is one of the most important sectors of the agricultural economy in Crete. Traditional Cretan cheeses, such as graviera, xinomizithra, and anthotyro, are widely recognized for their quality and cultural significance. However, modern cheese-making plants consume large amounts of energy and water while producing greenhouse gas emissions and industrial waste. As concerns about climate change continue to grow, the decarbonization of cheese-making plants in Crete has become an essential step toward sustainable food production and environmental protection. One of the primary environmental challenges faced by cheese-making plants is their high energy consumption. Dairy processing requires electricity and heat for refrigeration, milk pasteurization, storage, and packaging. Many facilities still rely on fossil fuels, which generate significant carbon dioxide emissions. To reduce their carbon footprint, cheese plants in Crete can transition to renewable energy sources such as solar and wind power. Crete has abundant sunshine throughout the year, making solar energy particularly suitable for industrial use. Installing photovoltaic systems on factory rooftops can help reduce dependence on conventional electricity while lowering operational costs over time. Another important aspect of decarbonization is improving energy efficiency within production facilities. Modernizing machinery, insulating cooling systems, and using energy-efficient equipment can significantly reduce electricity consumption. Smart monitoring technologies can also help factories track energy use and identify areas where resources are wasted. These improvements not only reduce emissions but also increase productivity and competitiveness in the dairy sector. Waste reduction and circular economy practices are also essential for decarbonization. Cheese production creates by-products such as whey, which is often considered waste. However, whey contains valuable nutrients and can be transformed into products such as animal feed, protein supplements, or bioenergy. Some cheese-making plants may even use anaerobic digestion systems to convert organic waste into biogas, which can then be used to produce heat or electricity for the factory itself. Such practices reduce waste disposal costs while contributing to cleaner energy production. Transportation and packaging are additional sources of carbon emissions. Refrigerated transport is necessary to maintain product quality, especially for exports outside Crete. Cheese-making plants can reduce emissions by optimizing logistics, using fuel-efficient vehicles, and sourcing raw materials locally. Furthermore, replacing plastic packaging with recyclable or biodegradable materials can help reduce environmental pollution and improve the sustainability image of Cretan dairy products. The decarbonization of cheese-making plants in Crete offers both environmental and economic benefits. Consumers increasingly prefer products made with sustainable practices, and environmentally responsible production can strengthen the international reputation of Cretan cheeses. Support from the European Union and national green transition programs can also help dairy industries finance investments in renewable energy and modern technologies. Therefore, reducing carbon emissions in cheese-making plants requires a combination of renewable energy use, efficient technologies, and waste recycling. By adopting greener industrial practices, Crete can preserve its traditional cheese-making heritage while contributing to global efforts against climate change and building a more sustainable future for the dairy industry. Table 1 indicates the zero carbon emission energy technologies that can be used in cheese making plants in Crete while Table 2 the characteristics of a small-scale cheese making plant in Crete achieving net-zero carbon emissions during its operation**.**

Table 1. Zero-carbon emission energy technologies that can be used in cheese making plants in Crete eliminating their carbon footprint

Energy source/fuel	Technology	Generated energy	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
Biogas produced by anaerobic digestion of cheese making wastes	Burning	Heat and electricity	No
Electricity	Electric batteries	Electricity	Yes
Heat	Phase change materials/heat storage tanks	Heat	Yes

Source: (26)

Table 2. Characteristics of a small-scale cheese making plant in Crete achieving 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$_p$
Heat capacity of solid biomass	4.2 kWh/kg
Nominal capacity of the solar-PV system generating the electricity demand in the plant	88 kW$_p$
Required quantity of solid biomass generating the heat required in the plant	62.86 tons/year

Source: (26)

5. DECARBONIZATION OF WINE-MAKING INDUSTRIES IN CRETE

Wine production is one of the oldest and most important agricultural traditions in Crete. The island's favorable climate, fertile soil, and indigenous grape varieties have allowed the wine industry to flourish for centuries. Today, Cretan wineries are gaining international recognition for producing high-quality wines while promoting local culture and tourism. However, wine-making plants also contribute to greenhouse gas emissions through energy consumption, transportation, packaging, and waste generation. As climate change increasingly threatens agricultural production and Mediterranean ecosystems, the decarbonization of wine-making plants in Crete has become a necessary step toward sustainable development. One of the main sources of carbon emissions in wineries is energy use during the wine production process. Wine-making plants require electricity for grape crushing, fermentation, cooling systems, bottling, and storage. Many facilities still depend on fossil-fuel-based electricity, which increases carbon dioxide emissions. To reduce their environmental impact, wineries in Crete can invest in renewable energy technologies such as solar panels and wind turbines. Since Crete receives abundant sunlight throughout the year, solar energy is especially suitable for powering winery operations. Renewable energy systems can significantly reduce emissions while lowering long-term operating costs. Improving energy efficiency within wine-making plants is another important strategy for decarbonization. Modern cooling systems, insulated storage areas, and energy-efficient machinery can help reduce electricity consumption. Smart energy management systems can monitor production processes and identify areas where energy is wasted. By adopting innovative technologies, wineries can improve productivity while minimizing their carbon footprint. Waste management plays a significant role in the decarbonization process. Wine production generates organic waste such as grape skins, seeds, and stems, commonly known as pomace. Instead of discarding these materials, wineries can use them to produce compost, animal feed, or bioenergy. Some wineries may also adopt circular economy practices by converting organic waste into biogas through anaerobic digestion systems. This renewable energy source can then be used within the winery itself, reducing dependence on fossil fuels. Packaging and transportation are additional contributors to carbon emissions in the wine industry. Glass bottles are energy-intensive to produce and transport because of their weight. To reduce emissions, wineries can use lighter bottles, recycled glass, or alternative packaging materials. Improving local distribution networks and reducing long-distance transportation can further decrease fuel consumption and environmental impact. The decarbonization of wine-making plants in Crete also offers important economic opportunities. Consumers worldwide are increasingly interested in environmentally sustainable products, and eco-friendly wine production can strengthen the reputation of Cretan wineries in international markets. Furthermore, European Union sustainability programs and green investment funds can support wineries in financing renewable energy systems and environmental technologies. Therefore, the transition toward low-carbon wine-making plants in Crete requires renewable energy adoption, efficient resource management, waste recycling, and sustainable packaging solutions. By embracing greener production methods, Cretan wineries can protect the environment, preserve traditional wine-making culture, and ensure the long-term sustainability of one of the island’s most valuable industries. Table 3 indicates the low-carbon energy technologies and fuels that can be used in Cretan wineries.

Table 3. Low-carbon energy technologies and fuels that can be used in Cretan wineries for eliminating their carbon footprint

Energy source/fuel	Technology	Generated energy	Current applications in Crete
Solar energy	Solar-thermal systems	Heat	Yes
Solar energy	Solar-PV systems	Electricity	Yes
Solid biomass	Solid biomass burning	Heat	Yes
Green electricity and ambient heat	Heat pumps	Heat and cooling	Yes
Green electricity	Electric batteries	Green electricity	Yes
Heat	Phase change materials/heat storage tanks	Heat	Yes

Source: (24)

6. DECARBONIZATION OF OLIVE OIL MILLS IN CRETE

Olive oil production is one of the most important economic and cultural activities in Crete. The island is responsible for a significant share of Greece’s olive oil output, and Cretan olive oil is internationally recognized for its quality, nutritional value, and connection to the Mediterranean diet. However, despite its “natural” image, olive oil production plants contribute to greenhouse gas emissions through energy use, water consumption, waste generation, and transportation. As climate change accelerates, the decarbonization of olive oil producing plants in Crete is becoming essential for ensuring both environmental sustainability and long-term competitiveness. One of the main sources of emissions in olive oil mills is energy consumption. The extraction process requires electricity and thermal energy for crushing olives, malaxation, centrifugation, filtration, and storage. Many traditional mills still rely on fossil fuel-based electricity or diesel-powered equipment, which increases carbon dioxide emissions. A key decarbonization strategy is the transition to renewable energy sources. Crete has exceptional solar potential, making photovoltaic systems a highly effective solution for powering olive oil plants. In addition, small-scale wind energy systems and hybrid renewable setups can help mills achieve near-carbon-neutral operations. Improving energy efficiency is another critical step. Modern olive oil processing equipment is significantly more efficient than older machinery, requiring less energy per unit of oil produced. Upgrading motors, pumps, and centrifuges, as well as optimizing production schedules, can reduce energy demand. Smart monitoring systems can also help identify inefficiencies and ensure that machines operate only when necessary, minimizing unnecessary energy consumption. Waste valorization is an important aspect of a circular economy approach. Olive pits, pulp, and other by-products can be converted into bioenergy, compost, or animal feed. Olive pomace, in particular, can be processed into biomass fuel, reducing reliance on fossil fuels for heating. By transforming waste into valuable resources, olive oil mills can significantly reduce their overall carbon footprint while creating additional economic value. Transportation and packaging also contribute to emissions. Olive oil distribution often requires long-distance transport, especially for export markets. Optimizing logistics, promoting local consumption, and using fuel-efficient or electric vehicles can help reduce emissions. On the packaging side, shifting to lightweight glass bottles, recycled materials, or bulk distribution systems can further lower environmental impact. The decarbonization of olive oil producing plants in Crete is not only an environmental necessity but also an economic opportunity. Consumers are increasingly demanding sustainably produced food, and carbon-neutral olive oil can strengthen Crete’s position in global markets. Support from European Union climate policies and green funding mechanisms can further accelerate this transition. Therefore, reducing emissions in olive oil production requires a combination of renewable energy adoption, energy efficiency improvements, circular economy practices, and sustainable logistics. By embracing these strategies, Cretan olive oil mills can preserve their traditional heritage while contributing to a low-carbon and environmentally resilient future. Table 4 indicates the renewable energy technologies that can be used in olive oil mills in Crete while Table 5 the characteristics of an olive oil mill in Crete with net-zero carbon emissions due to energy use.

Table 4. Renewable energies that can be used in olive oil mills in Crete for eliminating its carbon footprint

Energy source/fuel	Technology	Generated energy	Current applications in Crete
Solar energy	Solar photovoltaic modules	Electricity	Yes
Solar energy	Solar mirrors	Hot water	Yes
Olive kernel wood	Burning	Heat	Yes
Biogas produced from olive mill wastes	Cogeneration of heat and power	Electricity and heat	No
Green electricity	Electric batteries	Green electricity	Yes
Heat	Heat storage	Heat	Yes

Source: (25)

Table 5. Characteristics of an olive oil mill in Crete with net-zero carbon emissions during its operation

Parameter	Value
Olive oil production	200 tons/year
Electricity consumption	20,000 kWh_{el}/year
Heat consumption	40,000 kWh_{th}/year
Total energy consumption	60,000 kWh/year
Nominal power a of solar-PV system meeting all the annual power demand in the olive oil mill	13.33 kW_p
Quantity of olive kernel wood required to meet all the annual heat demand in the olive oil mill	9,524 kg/year

Source: (25)

7. SUSTAINABLE AND LOW-CARBON ENERGY TECHNOLOGIES WHICH CAN BE USED IN OLIVE OIL MILLS, CHEESE MAKING PLANTS AND WINE MAKING PLANTS IN THE ISLAND OF CRETE, GREECE

Several sustainable and low-carbon energy technologies can be used in several food industries in Crete for heat and electricity generation as well as for energy storage. The abundant solar irradiance in the island and the biomass produced from agricultural residues, by-products and wastes can meet all the energy demand in olive oil mills, cheese making plants and wine making plants in the island of Crete. Electricity can be generated via solar-PV systems and from cogeneration of heat and power systems using biogas which can be produced from anaerobic digestion of organic wastes of food industries. Heat can be produced from solid biomass burning, from cogeneration of heat and power systems and from solar thermal systems. Heat and cooling can be also produced from heat pumps while energy can be stored in electric batteries and in heat storage systems. The low- and zero-carbon energy technologies which can be used in olive oil mills, cheese making plants and wine making plants in the island of Crete, Greece are presented in Table 6.

Table 6. Low and zero-carbon energy technologies which can be used in olive oil mills, cheese making plants and wine making plants in the island of Crete, Greece

Energy source/fuel	Technology	Generated energy	Use in Crete
Solar energy	Photovoltaic modules	Electricity	Yes
Solar energy	Solar mirrors	Hot water	Yes
Solid biomass	Burning	Heat	Yes
Biogas produced by anaerobic digestion of wastes	Co-generation of heat and power	Heat and electricity	No
Ambient heat and electricity	Heat pumps	Heat and cooling	Yes
Electricity	Electric batteries	Electricity	Yes
Heat	Heat storage systems	Heat	Yes

Source: Own estimations

8. COMPARISON OF CARBON EMISSIONS IN THE ABOVEMENTIONED FOOD PROCESSING INDUSTRIES IN CRETE

The carbon emissions in olive oil mills, cheese making plants and wineries in Crete have been compared. Data from existing literature regarding emissions in these industries in several countries have been used to estimate the life-cycle emissions in cheese making plants and wineries and the carbon emissions in olive mills in Crete. Taking into account that most olive mills in Crete use solid biomass for heat production only the carbon emissions due to electricity consumption have been estimated. The results are presented in Table 7.

Table 7. Energy consumption and carbon emission in various food industries in Crete

Food industry	Energy consumption	Carbon emissions
Olive oil production	Electricity consumption in olive oil mills: 0.18 kWh/kg olive oil	Carbon emissions due to electricity consumption in olive oil mills: 0.04 $kgCO_{2e}$/kg olive oil
Cheese production	3.33 kWh/kg cheese	Life-cycle carbon emissions: 1.26-23.7 $kgCO_{2e}$/kg cheese
Wine production		Life-cycle carbon emissions: 1.6 $kgCO_{2e}$/l of bottled wine

Source: (24), (25), (26)

Table 7 indicates that the life-cycle carbon emissions in cheese and wine making plants are significantly higher than carbon emissions due to power demand in olive mills.

9. DISCUSSION

The low- and zero-carbon energy sources and fuels which can been used in several food industries in Crete including olive mills, wineries and cheese making plants have been stated. Additionally, the carbon emissions in these industries have been compared. Several studies in various countries have been conducted so far evaluating the energy consumption and carbon emissions in the abovementioned industries. It has been found that in general more heat than electricity is used in these plants. Their carbon emissions vary significantly depending on many factors including type of product, size of plant, country, system boundaries et cetera. The abundant solar energy and solid biomass resources in Crete allow their use for electricity and heat generation in these plants meeting all their operational energy requirements. Solar energy is broadly used in Crete for power generation with solar-PV systems while solid biomass produced from agricultural residues, by-products and wastes is currently used by burning for heat production. Solar thermal energy is broadly used in Crete and it can be used for hot water production covering part of the heating needs in these plants. High efficiency heat pumps powered by solar electricity can be used for heat and cooling production required in cheese and wine making plants. The liquid wastes of olive mills and cheese making plants can be used with anaerobic digestion for biogas production which can be used for cogeneration of heat and power meeting the energy needs in these plants. However, these technologies are not currently used nowadays in Crete. Transport of the food products can be achieved by electric vehicles with rechargeable batteries powered by solar electricity generated by solar-PV systems installed in these plants. However, electric mobility is limited nowadays in Crete. Our study gives qualitative results while the estimated carbon emissions are based on existing studies in similar plants conducted in other regions with different characteristics. Future work should be focused on implementing case studies estimating the energy consumption and carbon emissions in olive mills, wineries and cheese making plants operating in Crete. It should be also focused in performing case studies designing the renewable energy systems which could eliminate the carbon emissions in these plants.

10. CONCLUSIONS

The sustainable and low-carbon energy technologies which can be used in several food industries in the island of Crete, Greece including olive oil mills, cheese making plants and wine making plants promoting their decarbonization have been identified and the carbon emissions during olive oil, cheese and wine production in Crete have been compared. The results can be summarized as follows.

a) The abundant solar energy and solid biomass resources in Crete allow their use in olive mills, wineries and cheese making plants in Crete. Solar energy can be used for electricity generation with solar-PV systems and for heat production with solar thermal systems. Solid biomass can be used by burning for heat production while heat pumps powered with solar electricity can be used for heat and cooling generation.

b) The combined use of the abovementioned renewable energy technologies can meet all the heat, cooling and power demand in these industries eliminating their carbon footprint.

c) The carbon footprint per unit of product due to operational energy use in olive mills is lower than the carbon footprint in wineries and cheese making plants.

The key finding in our study is that the use of mature, reliable and cost-effective renewable energy technologies can eliminate the carbon footprint of several food industries in Crete achieving their decarbonization.

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