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The Interrelation Between Food, Water and Energy in the Island of Crete, Greece

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ABSTRACT: Water, energy and food are important resources for human well-being while their demand is expected to increase in the future. These resources are interrelated and interdependent while they are threatened from climate crisis and their unsustainable management. Climate change is expected to increase the water shortage in the island while climate change mitigation requires the extensive use of renewable energy sources, which are abundant in Crete, instead of fossil fuels. The study of their nexus and their synergies is neccessary for improving the sustainability in the island of Crete which hosts more than 6 million tourists annually. The nexus between water and energy, water and food and energy and food in Crete has been consecutively studied. The findings indicate a strong relationship between water to food, energy to food and energy to water. However the relationship between water to energy and food to water is weak in Crete. Our results could improve the management of these resources in Crete avoiding their undesired shortage in the future. The findings could be usefull to public and municipal authorities, to policy makers and to several stakeholders in the island who are related with these basic resources.

KEYWORDS: Crete-Greece, energy, food, interrelation, nexus, sustainability, water

1. INTRODUCTION

Water, energy and food consist of basic resources in human societies which are interrelated and interlinked [1], [2]. The use of these resources is expected to increase in the future while they are threatened from climate change and the human consumption [3], [4], [5], [6]. The nexus of these resources in many regions has been studied in order to explore their interactions, trade-offs and synergies [7], [8], [9]. The study of their nexus is particularly important in Mediterranean basin, an area which is affected significantly from climate crisis [10], [11], [12], [13].

The aim of the current study is to explore the nexus of water, energy and food in the island of Crete, Greece.

The text is structured as follows. After the literature review the concept of the water-energy-food (WEF) nexus is examined followed by the study of the interactions between water and food in Crete. In the next two sections the interactions between water and energy and energy and food are analyzed. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used. The study is innovative since there are not similar studies published for Greece while is filling a gap regarding the WEF nexus in the island of Crete, Greece which is affected significantly from climate crisis. The current study could be useful to local and regional policy makers, to farmers, to water management authorities in Crete as well as to several stakeholders related to these resources.

2. OVERVIEW OF RESEARCH TRENDS AND DEVELOPMENTS IN THE WATER-ENERGY-FOOD NEXUS

The evolution of scientific research on the Water-Energy-Food nexus has been extensively analyzed [1]. The authors reported a significant surge in WEF-related studies over the past decade. They highlighted that agriculture remains an underdeveloped concept within the nexus framework and emphasized the need to incorporate health considerations into WEF studies. A comprehensive review of WEF nexus research indicates its progression toward a more integrative approach, emphasizing interdisciplinary and intersectoral analysis [2]. A critical review underscores the potential for sustainable water, energy, and food security at the community level [3]. The authors proposed various key principles for future development, such as enhancing clarity, ensuring data reliability, and promoting adaptability across scales. Research has traced the WEF nexus's evolution since 2011, particularly in policy and development spheres [4]. While the framework holds promise, it faces significant challenges to widespread adoption. A novel approach supporting food security and sustainable agriculture through the WEF nexus framework underscores the essential role of water, energy, and food in human well-being and sustainable development [5]. Projections indicate an increasing demand for all three resources in the coming decades. A global assessment of the Food-Energy-Water (FEW) nexus identifies water availability as a key constraint in meeting future food and energy demands [6]. The study recognized increasing

competition between food and energy systems for limited water resources. A review of the advantages and limitations of the WEF nexus approach notes a regional focus in Asia and Africa, with most literature centered on food production [7]. The impacts though of dietary changes on food consumption are seldom addressed. Nexus assessment methodologies aiming to identify trade-offs and synergies among WEF systems, while incorporating social and environmental impacts to inform cross-sectoral policy development have been examined [8]. However, their application remains limited. From a sustainable development perspective, the WEF nexus provides a robust framework for addressing complex resource issues [9]. The authors stress that applying this framework in the Global South requires acknowledging it as a multi-scale, socio-institutional system influenced by historical and contextual factors. A study of the WEFE (Water-Energy-Food-Ecosystems) nexus in the Mediterranean region examines how water management decisions impact energy and food systems—resources that are critical for human well-being and climate resilience [10]. In the Mediterranean basin, WEFE nexus research is increasingly recognized as an innovative method for analyzing interdependencies [11]. A review of 142 articles revealed that water-energy interdependence dominates the regional research landscape. The relationship between the water footprint and the WEFE nexus in the Mediterranean shows significant challenges due to water scarcity [12]. The authors propose two methodologies for exploring synergies and trade-offs within the nexus. Regional WEF challenges in Mediterranean region have been exacerbated by climate change and geopolitical instability, such as the Ukraine conflict [13]. These factors intensify vulnerability in accessing essential resources. An investigation into the motivations, objectives, and methodologies of WEF studies reveals a broad range of research goals [14]. These include sustainability assessment, resource optimization, and evaluation of the impacts of resource consumption, among others. A review of WEF interactions quantified resource interdependencies, noting that theoretical studies explore more interactions than empirical ones [15]. Among six identified interactions, "water for food" emerged as the most commonly studied, while "food for water" was the least. The WEF nexus in relation to ecosystems and Sustainable Development Goals (SDGs) has been explored [16]. The approach advocates integrated management across sectors and views water, energy, food, and ecosystems as interconnected rather than isolated entities. An early literature review concluded that empirical research had yet to validate claims that nexus approaches improve resource management and governance outcomes, posing a significant challenge for the field [17]. A systematic review of WEF nexus governance emphasizes its rising importance across scientific, political, and economic agendas. The concept of "nexus governance" has emerged from intensified debates on resource management [18]. Research on governance gaps and needs highlights that rising demand and short-term, sector-specific resource management threaten sustainability. While nexus frameworks offer analytical value, they have not consistently translated into effective policymaking [19]. Stakeholder engagement is recognized as essential in addressing WEF nexus challenges [20]. The approach has gained traction as a powerful tool for analyzing system interdependencies and encouraging collaborative research. A policy review in Egypt, Italy, Spain, and Tunisia explores how demographic and economic changes are expected to increase WEF demands [21]. The study identifies key enablers and obstacles influencing policy effectiveness. Climate projections for the Mediterranean region—one of the most vulnerable to climate change—suggest a 2–3°C temperature increase and a 5–20% decrease in rainfall by 2050 [22]. These changes will significantly affect water availability and agricultural output. The WEF nexus's role in economic growth was studied in Mediterranean region, where climate change and human activity threaten water availability [23]. The authors advocate for an integrated approach to maximize resource efficiency through synergy analysis. A study focused on the eastern Mediterranean region explores how integrated WEF systems can address climate challenges [24]. Renewable energy is highlighted as a crucial factor in enhancing sectoral resilience. On the island of Crete, Greece, electricity is crucial for water services such as pumping and purification [25]. However, electricity generation on the island is not heavily dependent on freshwater resources. A study on Crete's water resource management shows that the island is generally water-sufficient under average weather conditions [26]. Agriculture accounts for 78% of total water use, followed by domestic consumption at 21%.

3. THE CONCEPT OF WATER-ENERGY-FOOD NEXUS

The Water-Energy-Food nexus represents the intricate and interdependent relationship between three critical resources essential for human survival and sustainable development. Water is required to produce energy, energy is essential to extract and distribute water, and both are vital in growing, processing, and transporting food. As global population increases and climate change intensifies, the demand for these resources grows, often leading to competing uses and resource scarcity. Understanding the WEF nexus is crucial for creating integrated policies that prevent unintended consequences. For instance, increasing biofuel production may reduce fossil fuel dependence but can lead to excessive water use and reduced food availability. Similarly, intensive agriculture may boost food security while straining water and energy supplies. A nexus approach promotes resource efficiency, encourages renewable energy use, supports climate resilience, and fosters cooperation across sectors. It emphasizes the need for systems thinking in policymaking, ensuring that progress in one domain does not hinder another. Ultimately, the WEF nexus highlights the need for holistic

management of natural resources to ensure sustainable development, economic stability, and environmental protection for current and future generations.

4. THE INTERACTIONS BETWEEN WATER AND FOOD IN THE ISLAND OF CRETE, GREECE

The island of Crete, the largest and most populous of the Greek islands, is a land of extraordinary natural beauty, deep-rooted cultural heritage, and agricultural abundance. Located in the eastern Mediterranean, Crete has long served as a cradle of civilization and a vital agricultural center for Greece. Today, the island continues to be a major contributor to the nation's food production, offering high-quality produce such as olives, grapes, citrus fruits, vegetables, and aromatic herbs. However, this agricultural prosperity is closely tied to the availability and management of freshwater resources. The nexus between water and food in Crete is a complex, dynamic relationship that presents both challenges and opportunities for sustainable development.

4.1 The Agricultural Importance of Crete

Agriculture plays a crucial role in the economic and social fabric of Crete. The island's terrain, characterized by mountainous regions, fertile valleys, and a Mediterranean climate, offers favorable conditions for diverse crop cultivation. Olive oil, in particular, is one of Crete's most prominent exports, with the island being home to some of the oldest olive groves in the world. Wine production, cheese-making, beekeeping, and vegetable farming are also deeply ingrained in the local economy and lifestyle. Crete hosts around one third of the agricultural greenhouses in the country. The traditional Cretan diet, renowned for its health benefits, relies heavily on locally sourced fruits, vegetables, legumes, and olive oil. This diet is both a cultural identity and a nutritional model celebrated globally. Several studies have indicated the importance of Mediterranean diet in the management of the global obesity pandemic. Yet, underpinning this agrarian success is a critical dependency on water—an increasingly scarce resource on the island.

4.2 Water Resources and Climatic Conditions

Crete's water resources are primarily sourced from rainfall, rivers, springs, and groundwater aquifers. However, the distribution of rainfall is highly uneven across the island. The western regions typically receive more precipitation than the eastern and southern parts, where aridity is more pronounced. The rainy season is largely limited to the winter months, and prolonged dry spells during the summer often place enormous pressure on water availability. Climate change has exacerbated these issues. Rising temperatures, shifting precipitation patterns, and increased frequency of droughts have intensified water stress in Crete. These changes threaten not only the sustainability of agriculture but also the balance of natural ecosystems and freshwater availability for households and tourism. The utilization of water resources in Crete is presented in table 1.

Table 1. Utilization of water resources in Crete

Sector	Annual water consumption (%)	Annual water consumption (mil M^3)	Annual water consumption per capita (M^3 per capita)
Agriculture	78.3	478.4	753.5
Domestic	20.9	127.6	201.0
Other	0.8	4.9	7.7
Total	100	610.9	962.2

Source: [26]

4.3 Agriculture and Water Use

Irrigated agriculture is by far the largest consumer of water in Crete, accounting at around 80% of total water use. Traditional irrigation practices, such as flood irrigation, are still used in many areas, leading to inefficient water use and wastage. Water is also necessary in the food and beverages processing industry. Over-extraction of groundwater has resulted in the depletion of aquifers and salinization, particularly in coastal regions where seawater intrusion has become a serious problem. The use of grey water from the treated effluents of municipal sewage treatment plants for crops' irrigation has not been developed satisfactorily in Crete. In recent years, there has been growing awareness and adoption of more water-efficient technologies. Drip irrigation systems, which deliver water directly to the plant roots with minimal evaporation loss, are gaining popularity among Cretan farmers. Additionally, greenhouse cultivation, especially in eastern Crete, has helped to increase water-use efficiency by controlling environmental conditions and reducing runoff. Agriculture and food processing can be a source of water pollution. Food and waste losses as well as poorly treated wastes from the food processing industry can pollute the surface and underground water resources.

4.4 The Role of Tourism in Water Demand

Tourism, a key pillar of Crete's economy, introduces another layer of complexity to the water-food nexus. The island welcomes millions of tourists annually, with the majority visiting during the summer months—precisely when water is scarcest and agricultural irrigation needs are highest. Hotels, restaurants, swimming pools, and golf courses significantly increase water consumption, particularly in coastal areas that often overlap with productive agricultural zones. The seasonal spike in water demand from tourism can lead to competition and conflict over water use. This situation calls for integrated water resource management strategies that

consider the demands of all sectors while prioritizing long-term sustainability.

4.5 Water Management Policies

Addressing water scarcity in Crete requires a multi-faceted and integrated approach. Over the past decade, several policy initiatives, infrastructure projects, and community-led efforts have emerged to mitigate water-related risks and promote sustainability. On the institutional level, the Greek government and regional authorities have collaborated with the European Union to implement water conservation programs under the Common Agricultural Policy and the EU Water Framework Directive. These programs aim to improve irrigation efficiency, protect water bodies from pollution, and promote sustainable land use. Innovative infrastructure projects, such as the construction of small dams, reservoirs, and desalination plants, have also contributed to more reliable water supplies, especially in regions with chronic shortages.

4.6 Looking Ahead: Toward a Sustainable Water-Food Future

The future of Crete's food security and environmental sustainability hinges on the island's ability to navigate the water-food nexus wisely. As pressures on water resources mount, the need for holistic planning becomes ever more urgent. Policymakers, farmers, scientists, and local communities must work together to ensure that water is used efficiently, equitably, and in harmony with the island's ecological capacity. Sustainable agriculture, supported by efficient irrigation, diversified cropping systems, and integrated water management, offers a pathway to resilience. At the same time, aligning tourism development with environmental sustainability—through eco-tourism, green certifications, and smart water technologies—can help balance economic growth with resource conservation. The nexus between water and food in Crete is a vital and multifaceted relationship that underpins the island's identity, economy, and future. Protecting this delicate balance is not merely an environmental necessity but a cultural imperative—ensuring that Crete remains a vibrant, fertile land for generations to come. The interrelation between water and food in Crete is presented in table 2.

Table 2. The interrelation between water and food in Crete

Water is necessary in crops' irrigation
Water is necessary in the food and beverage processing industry
The processed effluents from the sewage treatment plants in Crete can be used for crops' irrigation
Food and waste losses as well as poorly treated wastes from the food processing industry can pollute the surface and underground water resources

Source: own estimations

5. THE INTERACTIONS BETWEEN WATER AND ENERGY IN THE ISLAND OF CRETE, GREECE

The interconnected relationship between water and energy, often referred to as the "water-energy nexus," is a central theme in discussions surrounding sustainable development, especially in regions facing resource scarcity and environmental pressures. On the island of Crete this nexus holds critical importance. With its diverse topography, Mediterranean climate, growing population, thriving tourism industry, and ambitious renewable energy goals, Crete presents a unique case study in understanding how water and energy systems interact—and how they can be managed more sustainably in the face of climate change and socio-economic transformation.

5.1 Water for Energy: Hydropower and Beyond

Water plays a role in energy generation in Crete, though to a relatively limited extent compared to mainland Greece. The island lacks large rivers or expansive reservoirs that would enable high-output hydroelectric dams. Nevertheless, small-scale hydropower installations used to exist, mainly in western Crete where rainfall is more abundant and terrain supports the necessary elevation changes. These micro-hydropower plants contributed to the local energy mix and served as examples of decentralized, low-impact energy solutions. Water dams, such as Potamon dam located in Rethymno prefecture, can be used as hydro-pumped storage systems storing electricity which is necessary for increasing the penetration of renewable energies in the energy system of Crete. Water dams can be also used for photovoltaic power generation with the installation of floating solar modules on the water surface. Beyond direct generation, water is also essential for the cooling of power plants, especially in traditional oil-fired thermal power plants. Although Crete has transitioned significantly toward renewable energy, the island still hosts fossil-fuel-based power generation facilities, including diesel and oil-fired plants. These plants often rely on water for cooling, thereby linking their operation directly to water availability. Additionally, emerging energy technologies, such as hydrogen production or concentrated solar power could increase future demand for water depending on their scale and configuration. The sewage treatment plants in Chania and Heraklion produce biogas from the anaerobic treatment of the sludge which can be used for energy generation. Thus, even in the transition to clean

energy, the water footprint of various energy technologies must be carefully considered.

5.2 Energy for Water: Desalination, Pumping, and Distribution

Conversely, energy is vital for securing and distributing water in Crete. The energy demands of water infrastructure are especially evident in the operation of water pumping stations, water treatment plants, and desalination facilities. As freshwater availability becomes increasingly limited—particularly in eastern and southern parts of the island—desalination has emerged as a practical solution to ensure water supply for domestic and agricultural needs. Desalination, however, is energy-intensive. The most common method, reverse osmosis, requires significant electricity to force seawater through membranes that filter out salts and impurities. In Crete, where energy prices have traditionally been high due to reliance on imported fuels, desalination's costs can be prohibitive without government subsidies or renewable energy integration. Moreover, the mountainous terrain of the island means that transporting water from sources to urban centers or farmlands often requires energy-intensive pumping. In many areas, water must be lifted hundreds of meters in elevation, adding to energy consumption and operational costs. This makes the optimization of water distribution networks not just a hydraulic challenge but also an energy issue. Aditionally energy is required for the operation of the sewage treatment plants in Crete.

5.3 The Impact of Climate Change

Climate change poses a serious risk to both water and energy systems in Crete. Rising temperatures, decreased precipitation, and prolonged droughts are expected to reduce surface water flows and groundwater recharge, increasing pressure on already-stressed aquifers. At the same time, higher temperatures lead to increased electricity demand, especially during summer, for air conditioning and cooling systems. The simultaneous intensification of water scarcity and energy demand can create feedback loops that amplify vulnerabilities. For instance, more frequent droughts may require more desalination or groundwater pumping, both of which require more energy. Meanwhile, a spike in energy use during heatwaves could strain the electricity grid. This intersection of vulnerabilities highlights the need for climate-resilient planning that integrates both sectors. Adaptive strategies, such as improving water-use efficiency, expanding renewable energy generation, and developing integrated resource management systems, will be crucial to coping with these compound risks.

5.4 Crete's Renewable Energy Transition

Crete has emerged as a frontrunner in Greece's push toward renewable energy. The island has abundant wind and solar energy potential, and these resources are increasingly being harnessed through large-scale wind farms and photovoltaic installations. In fact, Crete generates around 30% of its electricity from renewables, and this share is expected to rise substantially in the coming years. The transition to renewables not only helps decarbonize the energy system but also offers co-benefits for the water sector. Solar and wind power have minimal water requirements compared to conventional power generation, thus reducing the water footprint of electricity production. This is particularly advantageous in water-scarce regions like Crete. Furthermore, projects are connecting Crete to mainland Greece's power grid via undersea cables. This interconnection will reduce reliance on oil-based local generation and allow for greater flexibility and stability in the energy system. The expansion of smart grids and energy storage solutions could further enhance the resilience of both energy and water infrastructures. The interactions between water and energy in the island of Crete are presented in table 3.

Table 3. Interrelations between water and energy in the island of Crete

Small-scale hydropower plants used to operate in western Crete
Potamon dam in Rethymno prefecture is planned to be used for a hydro-pumped storage system
Floating solar photovoltaics can be installed on the surface of water dams in Crete
Water is used for cooling of the diesel and oil-fired power plants in the island
Water is going to be used in the future for green hydrogen production in Crete
Biogas is produced in sewage treatment plants in Crete
Energy is required for the pumping of underground water and its distribution
Energy is required for the desalination of salty water in Crete
Energy is required for the operation of the sewage treatment plants in Crete

Source: own estimations

6. THE INTERACTIONS BETWEEN ENERGY AND FOOD IN THE ISLAND OF CRETE, GREECE

The interconnection between energy and food is a critical area of focus in sustainability discourse, particularly in regions with unique geographical, economic, and environmental characteristics. The energy-food nexus in Crete is explored by analyzing how energy systems influence agricultural practices, how food production impacts energy consumption,

and how the island can balance these sectors to move toward sustainable development.

6.1 Crete's Agricultural Landscape

Crete has long been one of Greece's most agriculturally productive regions. However, agriculture in Crete is also highly energy-dependent. From the use of diesel-powered machinery to the irrigation of crops in increasingly dry climates, the sector consumes significant amounts of energy. The intensification of agriculture, particularly for export-oriented markets and tourism-related demands, has led to increased energy inputs and a growing ecological footprint.

6.2 Energy Landscape and energy Transition in Crete

Crete's energy profile has been undergoing significant transformation. Historically, the island has depended on imported fossil fuels for its electricity generation, relying on autonomous thermal power stations that are both costly and environmentally damaging. However, Crete is now transitioning toward renewable energy sources (RES), particularly solar and wind power, which align well with its natural conditions. This shift presents both challenges and opportunities. On the one hand, renewable energy development can decrease energy costs for farmers and reduce the carbon intensity of food production. On the other hand, large-scale renewable energy installations—especially wind farms—can create land use conflicts with agriculture and raise concerns about biodiversity and landscape aesthetics, which are crucial to both agriculture and tourism. The fossil fuels and renewable energies currently used for energy generation in Crete, Greece are presented in table 4.

Table 4. Fossil fuels and renewable energies currently used for energy generation in Crete, Greece

Energy generated	Fuel/energy source	Type of fuel/energy source	Is the fuel or energy source locally produced or locally available?
Electricity	Fuel oil, diesel oil	Fossil fuels	No
Electricity	Solar photovoltaic energy, wind energy, hydro energy, biogas	Renewable energies	Yes
Heat	Fuel oil, diesel oil, biogas	Fossil fuels	No
Heat, cooling	Solar thermal energy, solid biomass, ambient heat, electricity	Renewable energies, grid electricity	Yes
Mechanical energy in vehicles' transportation	Dieasel oil, gasoline, LPG, electricity	Fossil fuels and renewable energies	No, only small quantities
Imported electricity via an undersea cable	Several fuels and energy sources	Fossil fuels and renewable energies	No

Source: own estimations

6.3 Irrigation and Water-Energy-Food Linkages

Water scarcity is one of the most pressing environmental concerns in Crete, exacerbated by climate change, over-extraction, and inefficient irrigation practices. Irrigation is essential for agriculture on the island, particularly for high-value crops like olives and vegetables. However, water extraction and distribution require substantial energy inputs, especially when groundwater pumping is involved. This situation illustrates a classic example of the water-energy-food nexus: energy is required to access and deliver water; water is necessary for food production; and all three elements are under pressure due to climate and economic factors. Improving irrigation efficiency, investing in energy-efficient water pumps, and adopting precision agriculture techniques are essential strategies for addressing these interlinked challenges.

6.4 Food Processing, Storage, and Distribution

Beyond primary production, energy also plays a critical role in food processing, storage, and distribution. Crete has a vibrant food processing sector that adds value to agricultural products, especially olive oil, cheese, and packaged herbs. These processes, however, are energy-intensive. Refrigeration, pasteurization, packaging, and transportation all require reliable and affordable energy. Tourism, which greatly amplifies demand for food products during peak seasons, further increases energy loads related to food logistics. Restaurants, hotels, and supermarkets often rely on energy-intensive cold chains and long supply routes, particularly when local supply is insufficient or irregular. Encouraging local food systems and improving energy efficiency in supply chains are key ways to reduce energy demand and enhance food system resilience.

6.5 Renewable Energy Integration in the Food Sector

Crete's renewable energy potential offers a promising avenue to decarbonize the food sector. Solar photovoltaic systems can power irrigation pumps, greenhouses, and cold storage units, reducing farmers' dependence on grid electricity or diesel generators. Biogas from agricultural wastes is another

underutilized opportunity, with potential to provide both energy and organic fertilizer. Fried vegetable oils from resturants can be recycled and processed to produce biodiesel used in vehicles as substitute to diesel oil. Agricultural by-products and residues can be used for heat production. Plantations on buildings' roofs reducing the energy consumption in buildings have not been developed so far in the urban environment in Crete. The combined production of food and electricity can be achieved with the use of agri-voltaics in the fields allowing the generation of solar power without limiting the crops' growth. Semi-transparent solar photovoltaic modules can be also installed on the roofs of agricultural greenhouses generating solar electricity without affecting the production of vegetables. Energy cooperatives and decentralized energy production models can empower rural communities, reduce costs, and foster innovation. The current legal framework allows in agricultural enterprises to generate the electricity that they consume, using renewable energies, becoming procumers and avoiding future fluctuations in energy prices. However, barriers such as regulatory complexity, limited technical expertise, and financing constraints need to be addressed to fully realize these benefits. Training programs, public-private partnerships, and targeted subsidies can facilitate the energy transition within Crete's food sector.

6.6 Policy Frameworks and Institutional Support

The Greek government and the European Union have introduced several initiatives that impact the energy-food nexus in Crete. The National Energy and Climate Plan and the Common Agricultural Policy both emphasize sustainability, efficiency, and rural development. These frameworks provide funding for renewable energy projects, energy-efficient technologies, and climate-smart agriculture. Local institutions, including the Region of Crete and university research centers, play a key role in adapting these policies to the island's specific context. Pilot projects, such as smart irrigation systems and agri-photovoltaics, demonstrate innovative solutions to the energy-food nexus. Encouraging multi-stakeholder collaboration between farmers, energy providers, researchers, and policymakers is essential for scaling up successful models. The interrelations between energy and food are presented in table 5.

Table 5. Interrelations between energy and food in Crete

Renewable energy generation such as wind energy and solar photovoltaic energy can create land use conflicts with agriculture and crops production
Irrigation of crops requires energy
Cultivation of several crops requires energy used in machinery
Cultivation of crops requires fertilizers which consume large amounts of energy in their production
Food processing, storage and distribution requires energy
Food byproducts and wastes can produce biogas via anaerobic fermentation
Fried vegetable oils from resturants can be recycled and processed to produce biodiesel
Agricultural by-products and residues can be used for heat production
Food and electricity can be produced simultaneously with the use of agri-voltaics in cultivated crops
Semi-transparent solar photovoltaics can be installed on the rooftop of agricultural greenhouses generating electricity without affecting crops' growth
Solar photovoltaics can be installed on the roof terrace in food processing industries meeting part or all of their electricity needs.

Source: own estimations

7. DISCUSSION

The nexus among water, energy and food in the island of Crete, Greece has been explored. The current climate crisis has undesired impacts in water availability and in food production in the island. Mitigation of climate crisis requires the lower use of fossil fuels and their replacement with renewable energy sources. Water, energy and food are essential resources in human societies and their management requires the study of their interrelations and synergies. Insular societies are more vulnerable in these essential resources compared to continental regions. Strong relations between water to food, energy to water and energy to food have been found in Crete. Due to current water scarcity in the island the use of water resources in agriculture should be optimized. Crops with low water requirements should be prioritized due to less water availability in the island in the future. Crops producing food for local demand should be prefered compared to food production for exports. The abundant renewable energy resources in Crete, particularly solar and wind enery, can minimize the use of fossil fuel generated energy in food production and in water management. Competitive use of the limited water resources between agriculture and energy have not been found in Crete. Our study examines only the qualititave relations among the abovementioned resources while it does not provide comparisons with other Mediterranean islands. Further research should be focused in comparing the water-energy-food nexus in Crete with the corresponding nexus in other

islands. It should also try to make quantitave estimations regarding the interrelation among water, energy and food in Crete.

8. CONCLUSIONS

The nexus among water, energy and food in the island of Crete, Greece has been studied. These resources are essential for the human well-being while climate crisis, which is acute in Mediterranean region, has harmful impacts on them threatening their availability. The resources are interrelated and their sustainable management requires the unveiling of their interconnections and synergies. It has been found that the nexus between water to food, energy to food and energy to water in Crete is important. Agriculture and energy are not competing for water resources in Crete since the use of water resources in energy production is minimal. It has been also found that the nexus of food to water is weak. The following suggestions can be made based on our results.

a) The infrastructure for rainwater collection and storage in Crete should be improved with the construction of water dams and small-scale systems collecting the rainwater in cisterns. More water desalination plants should be constructed while the grey water from sewage treatment plants should be reused in agriculture.
b) Taken into account the future water scarcity in the island the modern sustainable water saving technologies should be used in the irrigation of agricultural crops in Crete,
c) The crops cultivated in Crete should be focused on plants requiring minimal water resources,
d) The agricultural production in Crete, if possible, should be oriented to foods concumed in the local market instead of transporting them in markets outside the island,
e) The energy used in water management as well as in agriculture and food industry should be based on the abundant renewable energy resources in Crete instead on fossil fuels.

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