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The Nexus between Agriculture and Renewable Energy Sources in the Island of Crete, Greece

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ABSTRACT

The aim of the current work is the study of the nexus between agriculture and renewable energies in the island of Crete, Greece. Agriculture and the use of renewable energies for energy generation are important sectors of the Cretan economy. Various applications of renewable energy systems in rural areas of Crete are presented. Use of agricultural residues and by-products for fuel production and energy generation are also described. Solar energy, wind energy, biomass and small hydroelectric systems are used for electricity and heat generation in rural areas in the island. Various residues and by-products produced mainly by olive trees are used for heat generation. The links of agriculture and renewable energies in the island should be strengthened in the future. Use of renewable energies in Crete has positive impacts in climate change mitigation while the impacts of agriculture are both positive and negative. Both sectors have positive impacts in the development of rural areas in the island. Agriculture and renewable energy use constitute complementary sectors to the tourism industry which dominates the island's economy and they should be promoted in the future in order to achieve a multi-dimensional and equally balanced economic development in Crete.

Keywords: agriculture, biomass, Crete-Greece, environmental impacts, local development, nexus, renewable energy sources

1 Introduction

Agriculture was the main economic activity in the island of Crete during the past centuries surpassed during the last decades from the development of the tourism industry which currently constitutes the main economic activity in the island. Technological advances during the last few decades in renewable energy technologies have allowed the commercial use of benign energy sources for power and heat generation. The current work is focused on the nexus between agriculture and renewable energy sources in the island of Crete, Greece. Although the tourism industry is currently the main economic activity in the island, contributing to the generation of approximately 50% of its regional domestic product; both agriculture and use of locally available renewable energy sources consist of alternative economic activities which are important in the island's economy. Both are based in the utilization of the rich renewable local natural resources and both contribute to job creation and generation of income in areas other than the coastal areas where the tourism industry is based. Development of alternative economic activities in Crete other than tourism, which depends on many unpredicted parameters, is important for the island's long-term prosperity. Agriculture and use of renewable energy sources in rural communities create various synergies between them as well as with the tourism industry, contributing in the prosperity of rural areas in the island.

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2 Literature survey

2.1 Use of agricultural residues, by-products and wastes for energy generation

Bedoic et al, 2019 have estimated the agricultural residues, co-products and by-products in the EU. The authors estimated the wastes in four different sectors (animal, vegetables, fruits, cereals) during their production, processing and consumption. They found that during the period 2010-2016 their total amount in EU countries was 18.4 bil tones while their distribution in the four sectors was animals 31%, vegetables 44%, cereals 22% and fruits 2%. **Algieri et al, 2019** have estimated the potential of agricultural residues for energy generation in Calabria, Italy. The authors stated that in this region there are agricultural residues, livestock sewage and wastes from the agro-food industry which could be used for heat and power generation. They also mentioned that the available quantities can simultaneously provide electricity to 178,000 households and heat to 116,000 households. **Bentsen et al, 2013** have estimated the global potential of agricultural residues for energy and material production. The authors mentioned that the theoretical energy potential from selected crop residues corresponds at 15% of the global primary energy consumption or at 66% of the world's energy consumption for transport. **Nohebel, 2007** has investigated the use of agricultural residues for energy generation and for animal feed. The author stated that the amount of the residues is large and they can be used either for energy generation or for cattle feed. He suggested that from the land use perspective, it is better to produce energy from energy crops and use the residues for livestock feed. **Weiland, 2006** has studied the biomass digestion in agriculture. The author mentioned that microbial conversion of energy crops and organic wastes to biogas has become one of the most attractive technologies for energy production and waste treatment. He also stated that biogas production in the agricultural sector is a very fast growing market in many European countries. **Ahn et al, 2010** have investigated the potential of dry anaerobic digestion, with low water content, of mixtures composed by animal manure and switch-grass. The authors mentioned that dry digestion has the advantages of a smaller reactor volume and less production of wastewater. **Angelidaki et al, 2003** have studied the co-digestion of manure and organic wastes in biogas plants in Denmark. The authors stated that there are both large-scale centralized biogas plants and smaller farm-scale plants in the country. These plants co-digest animal manure together with various organic wastes to produce biogas. **Scarlat et al, 2011** have estimated the agricultural and forest residues for bio-energy production in Romania. The authors stated that the high amount of biomass resources in the country constitute a significant renewable resource for energy generation. They also mentioned that the residues could be better used in co-generation and district heating systems as well as in other advanced systems with high energy efficiency.

2.2 Biomass availability in Greece

Alatzas et al, 2019 have estimated the biomass potential from agricultural wastes for energy utilization in Greece. The authors mentioned that Crete produces annually 1,959,124 tons of agricultural residues. They also proposed the development of small-scale biomass gasification plants which could co-generate heat and electricity, covering the needs in the local communities. **Vambuka et al, 2002** have studied the energy exploitation of agricultural residues in Crete. Their estimations indicated that the energy potential of olive wood is 8,385,861 10^3 Gcal, of vine-shoots 459,984 10^3 Gcal, of citrus trees 117,082 10^3 Gcal and of olive kernels 792,467 10^3 Gcal. **Vourdoubas, 2002** has studied the possibility of bio-fuel production in Crete, Greece. The author stated that bio-fuels are not produced so far on the island. He also mentioned that research has been implemented concerning the production of bio-ethanol from carob and bio-diesel from fried vegetable oils. **Zabaniotou et al, 2007**

have investigated the use of alternative methods for energy exploitation of biomass in Northern Greece. The authors mentioned that biomass has a unique advantage to be able to provide solid, liquid and gaseous fuels that can be stored, transported and utilized far away from the point of origin. They also stated that the cost of energy utilization of biomass is high due to the cost of logistics concerning its collection, transport and storage. **Skoulou et al, 2007** have investigated the possibility of using agricultural and animal wastes for energy generation in Greece. The authors mentioned that thermo-chemical technologies including pyrolysis, gasification and combustion could be used for the energy exploitation of biomass resources. **Michopoulos et al, 2014** have studied the energy, environmental and economic impacts of replacing heating oil with biomass for heating buildings in Greece. The authors mentioned that replacement of the fuel is economically profitable. However, they stated, biomass use results in higher CO_2 and SO_2 emissions as well as in higher primary energy consumption. **Boukis et al, 2009** have studied the possibility of using the Greek biomass resources for energy and fuel production in order to achieve the national targets. The authors proposed the use of biomass resources in Greece for: a) solid bio-fuel (pellets-briquettes) production, b) generation of heat and power based on combustion technology, c) bio-ethanol production, and d) bio-diesel production. They mentioned that the necessary biomass resources can be provided with the replacement of conventional cultivations with novel energy crops. According to the **Greek Statistics Organization, 2016** the area of the total tree plantations in Crete during 2016 was 148,434 ha while the dominant tree plantations were olive trees in a cultivated area of 142,957 ha. **Mardikis et al, 2004** have estimated the agricultural biomass in Greece. The authors mentioned that approximately 3.8 mil. dry tones of agricultural residues are available, with 600,000 tones of agro-industrial residues and 2,000 M^3/day animal wastes. They also stated that energy crops have not been developed so far in Greece. **Nikolaou et al, 2002** have studied the characteristics and the geographical distribution of agricultural residues for energy production in Greece. The authors stated that the quantities of agricultural residues in Greece have been estimated at 4,304,117 dry tones per year. They also mentioned that approximately one third of agricultural residues are produced from perennial crops while olive tree pruning had the highest share among them.

2.3 Use of Renewable Energies in Rural Communities

Milousi et al, 2019 have investigated the environmental performance of two solar energy systems through a combined life cycle assessment and cost analysis. The authors stated that solar photovoltaics and solar thermal collectors are both currently used in small- and large-scale applications. They mentioned that their use in areas with high solar irradiance, like in Crete, can be financially viable even in the case of low feed-in-tariffs. **Colombo et al, 2013** have studied the use of renewable energies for the promotion of local development. The authors mentioned that the use of renewable energies in distributed generation systems can contribute in poverty reduction. They also stated that the utilization of renewable energy resources results in the preservation of the environment and in the creation of employment and income in rural communities. **Gigantidou, 2013** has reported on renewable energy development in Crete. The author stated that during the last 15 years a significant number of wind turbines and solar-PV systems have been installed in the island. She mentioned that a high percentage of electricity consumption in Crete is generated by solar and wind energy systems. **Gkouskos et al, 2011** have reported on solar energy applications in Crete, Greece. The authors mentioned that the installed power, in 2011, of wind parks in Crete was 167 MW while that of PV stations was 33 MW. They also stated that two solar thermal cooling systems have been installed in two hotels in Crete. **Karnavas, 2006** has reviewed the autonomous electrical system of Crete. The author mentioned that its power system is a large autonomous system characterized by seasonal variations in the demand and the high increasing rate of its capacity by 8% annually. He also

gave an overall view of the system including its generation units, substations, wind parks and the grid. **Vourdoubas, 2015** has reported on the present and future uses of biomass for energy generation in the island of Crete, Greece. The author mentioned that locally produced solid biomass is used for heat generation in buildings, greenhouses and in industry. He also stated that small quantities of biogas are used for co-generation of heat and power while bio-fuels are not currently produced in Crete. A report on the power system of Crete has been published by **DEDDIE, 2018.** According to this report, the electricity generation in Crete during 2018 was 3,042.8 GWh while 510,059 MWh were generated by wind farms and 134,808 MWh by solar-PV systems. In the same year 41 wind farms were operating in the island with a total nominal power at 202.36 MW. **Qiao et al, 2019** have studied the nexus among agriculture, economic growth and renewable energies in G20 countries. The authors stated that agriculture is the world's second largest greenhouse gas emitter. They mentioned that agriculture significantly increases CO_2 emissions in G20 countries while renewable energy consumption decreases CO_2 emissions in these countries. **A report on the production and use of renewable energies on the farm, 2019**, has been published. The report mentioned that different forms of renewable energy are produced in rural areas including solar energy, wind energy, geothermal energy and various types of bio-energy. Different technologies are available and cost-effective for generation of electricity, heat and fuel covering the energy needs in the farms. A report on energy and agriculture nexus has been published by **FAO, 2000.** The report mentioned that an integrated approach should be developed to exploit the synergies and the dual role of agriculture as an energy user and an energy supplier. The links between energy and agriculture are important for the rural development and the environmental sustainability. **A report on solar thermal markets in Europe, 2015**, has been published. The report mentioned that the installed solar thermal systems in 2014 in Greece were 0.39 m^2 of flat plate collector per capita. The total collector area of the installed solar thermal systems in Crete in 2014 were 266,342 m^2 while their total power was 186,439 KW_{th} (0.7 KW_{th} per m^2 of collector area).

The aims of the current research are:

a) The description of various renewable energy systems located in rural areas in Crete used for energy generation,
b) The description of biomass to energy technologies used in Crete for energy generation, and
c) The study of the links between agriculture and renewable energies as well as their impacts in rural development and environmental sustainability in Crete.

The methodology used initially included a literature review followed by the presentation of the existing renewable energy systems in Crete. Next, the rural biomass resources used for energy generation in Crete are presented, followed by an assessment of the impacts of agriculture and renewable energies on carbon emissions and on rural development in the island. Finally the discussion of the findings and the conclusions drawn are presented, together with suggestions for further research.

3 Energy generation by renewable energies in Crete

Heat and electricity is generated in the island with various renewable energy systems which in most cases are located in rural areas. These include:

a) Solar heating systems producing hot water which is mainly used in buildings including residential buildings and hotels located in rural areas as well as in agriculture. Exploitation of solar thermal energy in industrial applications in Crete is rather limited.

b) Solar-photovoltaic systems generating electricity. These include either stand-alone systems located in the fields generating electricity for the grid or systems installed in buildings, warehouses, agro-food industries, etc, with the net-metering regulations offsetting part or all of their electricity consumption. Few solar-PV systems are also powering buildings located in remote areas which are not grid-connected.

c) Wind turbines generating electricity which are installed on-shore in hills or mountains.

d) Small hydroelectricity plants generating electricity. Two small hydroelectric plants are located in rural areas in the western part of Crete while a larger hydroelectric plant is under construction in the middle of the island.

e) Solid biomass use for heat generation in buildings, greenhouses and agro-industries. The main source of solid biomass is the olive tree and either olive tree wood or olive kernel wood is used in various heat generation systems. Olive kernel wood is also processed locally producing olive biomass, a refined higher quality fuel used for heat generation.

The renewable energy sources and technologies used in rural areas in Crete for energy generation are presented in Table 1, while their overall installed power is presented in Table 2.

Table 1. Renewable energies used in rural areas in Crete for energy generation.

Renewable energy source	Technology	Energy generated	Use of generated energy
Solar energy	Flat plate collectors	Heat, hot water	Buildings, hotels, agricultural applications
Solar energy	Photovoltaic panels	Electricity	Electric grid, buildings, hotels, agricultural applications
Wind energy	Wind turbines	Electricity	Electric grid
Hydro energy	Hydroelectric plants	Electricity	Electric grid
Solid biomass	Burning in stoves, wood-fires, etc.	Heat, hot water	Buildings, hotels, agricultural applications, greenhouses, agro-food industries

Source: Own estimations

Table 2. Installed power of renewable energy systems in Crete

Energy system	Total installed power
Solar-PV	97 MW_{el}
Solar thermal	186.4 MW_{th}
Wind turbines	202.4 MW_{el}
Hydro-electric systems	< 1 MW_{el}

Sources: Solar thermal markets in Europe, trends and market statistics 2014; Gigantidou, 2013; DEDDIE, 2018

4 Use of Agricultural Products, by-Products and Residues for Energy Generation in Crete

Agriculture is simultaneously an energy user and an energy supplier. Various types of agricultural products, residues, by-products and wastes are used with various technologies for heat and electricity generation as well as for solid, liquid or gaseous fuel production. Energy crops for bio-ethanol and bio-

diesel production have not been developed so far in Crete. The main biomass resources used for solid bio-fuel production in the island are olive tree by-products and residues. The olive tree is currently the main tree cultivated in Crete dominating the island's perennial crops. Additionally, by-products and residues from other tree species including citrus are also used for energy generation. The existing perennial tree plantations in Crete are presented in Table 3.

Table 3. Perennial tree plantations in Crete (2016)

Tree plantation	Cultivated area (ha)
Olive tree plantations	142,957
Temperate climate tree plantations	630
Subtropical climate tree plantations	565
Citrus tree plantations	3,313
Total	147,465

Source: www.statistics.gr

Taking into account that few small-size animal breeding farms are operating in the island, animal manure is not used for biogas production. The number of animals bred in Crete are presented in Table 4.

Table 4. Number of animals in Crete (2009)

Animal	Number
cattle	2,403
sheep	1,877,680
goat	632,523
pig	46,738
rabbit	294,925
hen	1,818,466

Source: www.statistics.gr

Past efforts to utilize liquid olive mill wastes through anaerobic digestion for biogas production were not successful due to cost reasons. Therefore agricultural biomass resources are currently used in rural areas in the island only for heat generation while electricity, liquid or gaseous fuels are not currently produced. Biomass to energy related technologies which are used in Crete are presented in Table 5.

Table 5. Energy generation from different biomass resources with various technologies.

Biomass resource	Technology	Energy/fuel produced	Current use in Crete
Wood residues and by-products	Combustion	Heat, solid fuel, electricity	Yes, not for electricity generation
Wood residues and by-products	Pyrolysis	Fuels	No
Wood residues and by-products	Gasification	Fuels	No
Energy crop	Fermentation	Bio-ethanol	No
Energy crop	Chemical treatment	Bio-diesel	No
Animal manure	Anaerobic digestion	Biogas	No
Wastes from agro-food industries (olive mills, dairy etc)	Anaerobic digestion	Biogas	No

Source: Own estimations

5 Impacts of Agriculture and Renewable Energy Use on Carbon Emissions in Crete

Agriculture requires energy and fuels for the machinery used during cultivation, harvesting, transporting and processing various products. Energy is also consumed during the production of agro-chemicals, fertilizers and pesticides used in the cultivated fields. Most of the energy and fuels used originate from fossil fuels, resulting in greenhouse gas emissions into the atmosphere. Additionally, during animal breeding, methane is emitted into the atmosphere. Residues, by-products and wastes from agriculture are used for energy generation, replacing fossil fuels and decreasing carbon emissions. Agriculture has a dual role in climate change, both as an atmospheric greenhouse gases emitter and remover. Plants and trees, during their growth, through photosynthesis, remove CO_2 from the atmosphere to produce organic matter. In some cases, the role of agriculture in climate change mitigation could be more important than its role in food production. Use of renewable energies in various stages of foodstuff production, processing and transportation as well as use of precision agriculture to minimize the consumption of agro-chemicals and other resources could reduce the carbon emissions in the primary sector. Use of renewable energy sources for heat and power generation in Crete replacing fossil fuels results in lower carbon emissions into the atmosphere. Therefore both agriculture and renewable energy deployment can be conceived as activities which contribute to climate change mitigation.

6 Impacts of Agriculture and Renewable Energy use on Rural Development in Crete

Agriculture and cattle breeding are the main economic activities in rural areas in Crete. Due to the beautiful landscape in the traditional villages of the island, agriculture is combined with the development of agro-tourism which offers an additional income to the local inhabitants. Agricultural residues and by-products are also used for the production of biomass-based renewable fuels used mainly for heat generation. Collection, transportation and processing of the local biomass resources increase the local employment and the local income. Realization of various renewable energy systems for electricity generation in rural areas offers another possibility for investments, job creation and additional income in Crete. Installation and maintenance of these renewable energy systems also results in job creation in rural areas. Therefore agriculture, cattle breeding and use of renewable energy systems for energy generation offer the opportunity for developing activities in rural areas in Crete which are different to the tourism industry which is currently the dominant economic activity in the island.

7 Discussion

The results indicate the there is a nexus between agriculture and renewable energies in the island of Crete. Renewable energy systems are operating in rural areas, generating heat and electricity partly used in agricultural activities, while agricultural residues and by-products are used for solid fuel production and heat generation. Both are contributing to rural development and in environmental improvement while they consist of alternative activities to the tourism industry, creating new jobs and income to local residents. Agriculture and renewable energies also have synergies with the tourism industry in the island. Agro-tourism development offers an alternative option to mass tourism while local agricultural products are consumed by the tourists promoting the famous Cretan gastronomy and diet. Electricity generated by solar and wind energy systems is partly consumed in hotels while hotels have installed renewable energy systems in their premises for heat and electricity generation, covering part of their requirements. Our results do not reveal the way to promote the nexus between

agriculture and renewable energies in Crete. However, the use of agriculture residues, by-products and wastes for energy and fuel production should be encouraged using new technologies which are currently mature and cost-effective. At the same time, new applications of renewable energy technologies in rural areas should also be encouraged, producing more green energy in Crete.

8 Conclusions

The nexus between agriculture and renewable energies in the island of Crete, Greece has been studied. Both are important for the economy of Crete while there are many synergies between them. Various renewable energy sources are used in rural areas for heat and electricity generation, including solar and wind energy, biomass and hydro-energy, due to the abundance of renewable energies in the island. Agricultural residues and by-products are used for solid fuel production and heat generation by combustion while the olive tree is the dominant biomass source for energy generation. Agriculture has positive and negative impacts in atmospheric carbon emissions. It requires energy produced by fossil fuels, resulting in carbon emissions into the atmosphere, while it is the source of renewable carbon-free fuel production used in energy generation. At the same time, agriculture contributes to atmospheric carbon sequestration through photosynthesis during plant growth. Electricity and heat generation from renewable energy systems in rural areas results in lower use of fossil fuels and in less atmospheric carbon emissions. Agriculture and use of renewable energies in rural areas has positive impacts in local development, contributing to new opportunities for job creation, thereby increasing the income of the local population. Further research should be focused in the identification of new applications of renewable energies in the rural areas of the island. Additionally, the increase in the links and the synergies between agriculture and benign energy sources in Crete should be further studied.

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