Macrothink Institute™

Environmental Management and Sustainable Development
ISSN 2164-7682
2022, Vol. 11, No. 3

Climate Change Impacts on Energy Generation from Renewable Energies in the Island of Crete, Greece

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Received: May 4, 2022 Accepted: June 4, 2022 Published: June 10, 2022

doi:10.5296/emsd.v11i3.19830 URL: https://doi.org/10.5296/emsd.v11i3.19830

Abstract

Renewable energies are expected to have a central role in the future zero carbon economy. However, their energy potential is affected by climate change. The current work investigates the future impacts of climate change on the energy potential of several renewable energies including solar energy, wind energy, biomass and hydro energy in the island of Crete, Greece. Previous research worldwide has indicated that climate change is going to affect positively or negatively the potential of various renewable energies while the impacts are different in various geographical areas. The goal of the current study is the evaluation of the impacts of climate change on the energy potential of solar energy, wind energy, hydro energy and biomass in the island of Crete. Our results indicated that climate change during 21th century is expected to increase the solar energy potential in Crete by around 4% while the wind energy potential is going to decrease by 6-12%. A slight decrease in annual precipitation in the island is foreseen while the agriculture and forest-related solid biomass potential is expected to decrease due to more frequent forest fires, more droughts and land desertification. Climate change is not going to affect significantly the potential of the rich solar and wind energy resources in Crete. The findings of the present study could be useful in sizing the new renewable energy systems in Crete which are required to generate the "carbon-free energy" in the emerging "zero-carbon economy" by 2050.

Keywords: biomass, climate change, Crete-Greece, energy, hydro, impacts, solar, wind

1. Introduction

Climate change is the most severe environmental burden worldwide causing many catastrophes in developed and developing countries. Substitution of fossil fuels by renewable energies is considered as an efficient method for the reduction of emissions of undesired gases and the mitigation of greenhouse effect. However, climate change affects positively or negatively the potential of renewable energies to produce heat and electricity. Changes in air

temperature, solar radiation, precipitation, wind speed, atmospheric CO_2 concentration, droughts and land desertification alter the potential and the capacity of renewable energies to generate useful energy. The changes are different in various geographical areas of the world. The present work investigates the impacts of climate change on the energy potential of several renewable energies currently used for heat and electricity generation in the island of Crete, Greece. More specifically the qualitative impacts on solar energy, wind energy, biomass and hydro energy potential in the island are examined based on existing studies concerning climate change in European territories. Our research is important since it indicates weather the climate change will affect the energy potential of renewable energies in the island of Crete and their capacity to generate zero carbon heat and electricity. Taking into account that renewable energies are expected to generate most of the energy demand in the future any changes in their potential to generate energy will affect the size of the required renewable energy systems.

2. Literature Survey

The literature survey is separated in two parts including: a) the current use of renewable energies for heat and power generation in Crete and b) the impacts of climate change on the energy potential of renewable energies in Europe.

2.1 Use of Renewable Energies in the Island of Crete, Greece

Katsaprakakis et al, 2019 have studied the energy independence of Crete. The authors mentioned that high penetration of renewable energies in the energy system of Crete can only be achieved with electricity storage in pump hydro storage systems. They have identified 14 candidate sites in the island for creating pump hydro storage systems estimating their cost of construction at around 30 €/KWh. *Vourdoubas, 2020* has studied the use of renewable energy systems in rural areas in the island of Crete, Greece. The author mentioned several applications of renewable energy technologies for heat and electricity generation including the use of solar energy, wind energy, hydro-electricity, solid biomass and biogas. *Vourdoubas, 2015* has examined the present and future uses of biomass for energy generation in Crete. The author stated that biomass in Crete had a share at 6.4% in the total energy mix. He also mentioned that currently solid biomass is used for heat production while biogas for heat and electricity co-generation. An annual report of the electric system in Crete has been published by the *Hellenic Electricity Distribution Network Operator, 2018*. It was mentioned that the total electricity consumption in Crete in 2018 was at 3 043 GWh. The main fuels used were fuel oil and diesel oil. Additionally, solar energy, wind energy, biomass and hydro energy were also used in the island. *Vamvuka et al, 2002* have studied the use of agricultural residues for energy generation in Crete. The authors stated that the main agricultural residues used for heat generation in the island were produced from olive trees, citrus trees, vineyard pruning, and greenhouse's residues. *Gigantidou, 2013* has studied the use of renewable energies for power generation in Crete. The author stated that island of Crete is a living laboratory for examining the impacts of high penetration of renewable energies into its electric grid. *Chatziargiriou et al, 2016* have studied the development of renewable energies in Greek islands. The authors stated that renewable energies offer an excellent opportunity for

economic development in islands. Both citizens and the local communities will benefit from their deployment while they identified four success factors for their successful promotion including technology, governance, entrepreneurship and local participation. *Tsagarakis et al, 2004* have examined the water resources management in Crete including its recycling and reuse. The authors stated that the mean annual water precipitation in the island was estimated at 923 mm. *Alatzas et al, 2019* have estimated the agriculture-related biomass potential in several Greek regions, including Crete, for energy generation mentioning that the annual agriculture-related solid biomass in Crete is at 3 144 tons/capita. *Kagarakis, 1987* has estimated the values of solar irradiance in various areas in Crete. He stated that the annual solar irradiance in Crete varies in the range of 1 691 KWh/m^2 to 1 821 KWh/m^2 in panels' tilt at 30^o. *Fantidis et al, 2013* have estimated the energy generation by wind turbines in various locations in Greece. The authors stated that that the mean annual wind velocity in several sites in Crete was estimated in the range of 3.52 m/sec to 7.38 m/sec.

2.2 Impacts of Climate Change on Energy Generation by Renewable Energies in Europe

Hueging et al, 2013 have studied the changes in wind power generation over Europe until the end of 21st century using two climate models. The authors stated that their results indicated that on central and northern Europe the wind energy potential is going to increase particularly in winter and autumn. In contrast, in southern-Europe it is going to decrease in all seasons except in the Aegean-sea area. *Harbel et al, 2011* have estimated the global agriculture-related bioenergy potential in 2050 based on FAO projections. The authors mentioned that the agriculture-related bioenergy in 2050 is highly sensitive in climate change as well as the yields of agricultural products. *Solaun et al, 2019* have reviewed many studies related with the impacts of climate change on renewable energy generation worldwide. The authors stated that more studies have been realized for Europe than for other parts of the world while the majority of these studies are related with the impacts on wind and hydro energy. They mentioned that climate change has positive impacts on wind energy and biomass potential in northern Europe while the impacts in southern Europe are negative. The impacts on solar energy potential are geographically opposite. They also stated that the uncertainties regarding the evolution of the benign energy technologies over long-time are high. *Gaetani et al, 2014* have investigated the future energy productivity of solar-PVs in Europe and Africa with simulations using two climate change models. The authors stated that, under their assumptions, a significant increase in solar electricity generation up to 10% was observed in Eastern Mediterranean region. *Panagea et al, 2014* have studied the impacts of climate change on photovoltaic electricity generation in Greece. The authors mentioned that changes in solar irradiance and air temperature affect the solar-PV's productivity. Their results indicated that the total electricity output will be increased by around 4%. *Devis et al, 2018* have investigated the future changes in wind speed and in wind turbine's performance in Europe until 2050. The authors stated that in northern Europe and in northeastern Europe wind speeds are going to increase in summer and winter by 2-4% while in Mediterranean basin they are going to decrease by 3-6%. In this area a lower power generation at around 6-12% in the winter is foreseen. *Hosking et al, 2018* have studied the future changes in European wind energy potential assuming that the air-temperatures will be higher at 1.5^{o}C

compared to present values. The authors stated that the wind energy potential in northern Europe will increase while in southern Europe it will slightly decrease. *Tobin et al, 2018* have studied the vulnerabilities and resilience of renewable energy's power generation in Europe with air-temperatures higher at 1.5^{o}C, 2^{o}C and 3^{o}C compared to current levels. The authors stated that climate change has negative impacts on electricity production in most countries for most technologies while the impacts are more severe in southern Europe than in northern Europe. They also mentioned that the impacts are relative limited for solar-PV and wind power potential that may reduce up to 10%. *Jerez et al, 2015* have investigated the impact of climate change on photovoltaic energy generation in Europe using computer simulations. The authors stated that changes in energy generation in the range of -14% to +2% have been found. Comparing the period 2070-2100 with the period 1970-2000 the authors mentioned that the largest decrease has been noticed in northern countries while slightly positive increases have been estimated in southern countries. They concluded that these small changes in energy generation are not threatening the EU's solar-PV sector. *Cosentino et al, 2012* have studied the impacts of climate change on the yields of various energy crops in Europe. The authors stated that by 2030 yields are expected to increase in northern Europe due both to climate change and technological development. On the contrary, in southern Europe yields are going to be affected negatively due to climate change and positively due to technological development. *Tapoglou et al, 2019* have examined the impacts of climate change on extreme hydrological and meteorological events in Crete over the next 100 years. The authors mentioned that increased periods of droughts are foreseen in the future. *Morianou et al, 2018* have investigated the climate change-related desertification in Crete that affects agricultural crops and their fertility. The authors stated that 37% of land's area is characterized as sensitive to desertification while the western part of the island is less sensitive than the eastern part. *Giannakopoulos et al, 2009* have studied the climate change impacts in Greece in the near future. The authors' findings indicated: a) more dry days per year, b) more frequent fires in forests, c) more frequent droughts and land desertification, d) more frequent and intense extreme climate change-related events, e) higher levels of aerosol pollution, f) increase in precipitation in some areas and decrease in others, g) Higher temperatures, and h) increasing energy demand for cooling in the summer. *Lehner et al, 2005* have studied the impact of climate change on the hydropower potential in Europe. The authors stated that under a moderate climate change scenario the hydropower potential in southern and southeastern Europe in expected to decrease by at least 25%. The impacts of climate change on the potential of renewable energies in Europe according to previously mentioned studies are presented in table 1.

Table 1. Impacts of climate change on the potential of various renewable energies in Europe according to existing studies

Authors, year	Region	Results
Hueging et al, 2013	Europe	The wind energy potential is going to increase in northern and central Europe while is going to decrease in southern Europe except in Aegean-sea
Solaun et al, 2019	Europe	Positive impacts of climate change in wind energy and biomass potential in northern Europe and negative impacts in southern Europe. The impacts of solar energy potential are geographically opposite
Gaetani et al, 2014	Europe	The potential of solar-PV electricity will increase in eastern Mediterranean region
Panagea et al, 2014	Greece	The potential of solar-PV electricity will increase
Devis et al, 2018	Europe	Increase in wind energy potential in northern and northeastern Europe and decrease in Mediterranean basin
Hosking et al, 2018	Europe	Increase in wind energy potential in northern Europe and decrease in southern Europe
Tobin et al, 2018	Europe	Solar-PV and wind energy potential may decrease up to 10%
Jerez et al, 2015	Europe	Decrease in solar-PV potential in northern Europe and slight increase in southern Europe
Cosentini et al, 2012	Europe	Yields of energy crops are going to increase in northern Europe
Tapoglou et al, 2019	Crete	Increased periods of droughts in the future
Morianon et al, 2018	Crete	High sensitivity in land desertification
Giannakopoulos et al, 2009	Greece	Changes in climate conditions
Lehner et al, 2005	Europe	Hydropower in southern and southeastern Europe is going to decrease by at least 25%

Source: Various authors

Aims of the current work are:

a) to study the contribution of various renewable energies in energy generation in Crete, and

b) to investigate the climate change impacts on energy potential of various renewable energies comprising solar energy, wind energy, biomass and hydro energy in the island of Crete.

The text is structured as follows. After the introduction and the literature survey the use of renewable energies for energy generation in Crete is examined. Next the impacts of climate change in Crete are mentioned followed by an estimation of the renewable energy potential in the island and the climate change impacts on it based on the existing studies. After that the discussion of the findings and the conclusions drawn are presented while in the end of the text the references used in the present study are cited.

3. Use of Renewable Energies for Heat and Electricity Generation in Crete

Island of Crete like many other islands has abundant renewable energy resources that can be used for energy generation. Among them solar energy, wind energy and biomass are extensively used for heat and power generation. The potential of hydro energy and geothermal energy in Crete is low and their exploitation for energy generation is limited so far. The high potential of solar and wind energy increases the investors' interest for electricity generation via wind farms and solar-PV systems. However, taking into account that the electric grid in the island was autonomous there was an upper limit, for grid stability reasons, regarding the maximum installed power of solar and wind power systems in Crete. Currently the interconnection of the electric grids of Crete and continental Greece with two undersea

electric cables is under implementation while it is expected that more solar-PV systems and wind farms will be installed in Crete after its finalization. The installed power and the energy generation from renewable energies in Crete, in 2018, are presented in table 2. Carbon-free electricity is mainly generated by solar-PV systems installed both in the fields and in buildings' roofs as well as by on-shore wind parks. Additionally, hot water at around 50-70^{o}C is generated by solar thermosiphonic systems which is mainly used in buildings. The electricity generation from various fuels in Crete, in 2018, is presented in table 3. The contribution of hydro energy, biogas and geothermal fluids in energy generation is insignificant. The contribution of renewable energies had a share at 21.20% in the total electricity generation (2018) while the rest was generated by oil fuels imported in the island. The main biomass resources used for energy generation in Crete are presented in table 4. The most of them are based on agricultural residues, by-products and wastes while they are mainly used for heat production.

Table 2. Installed power of various renewable energies in Crete (2018)

Energy source	Energy generated	Installed power	Electricity generation (MWh)	%, of total electricity generation in the island
Solar-PV	Electricity	95.5 MW_{el}	134 808	4.43
Solar thermal	Heat	186.4 MW_{th}		
Wind	Electricity	200.3 MW_{el}	510 059	16.76
Hydro	Electricity	0.6 MW_{el}	257	0.01
Biogas	Electricity	< 1 MW_{el}	-	-
Solid biomass	Heat	-	-	-
Total	Electricity	296.4 MW_{el}	645 124	21.20
Fuel and diesel oil - thermal power stations	Electricity	824.6 MW_{el}	2 397 682	78.80

Source: Vourdoubas, 2020, HEDNO, 2018

Table 3. Electricity generation from various fuels and renewable energies in Crete (2018)

Energy source-fuel	Electricity generation (MWh)	%, of total
Fuel oil	1 762 612	57.93
Diesel oil	635 070	20.87
Renewable energies	645 123	21.20
Total	3 042 805	100

Source: HEDNO, 2018

Table 4. Main biomass sources used for energy generation in Crete

Biomass source	Biomass used for energy and fuels generation	Energy and fuels generated
Based on agriculture	Residues and by-products of olive and citrus trees	Heat
Based on agriculture	Various residues from vineyards, greenhouses and other crops	Heat
Based on forests	Various residues	Heat
Wastes from restaurants	Fried vegetable oils	Bio-diesel
Organic matter based on various wastes	Biogas produced from anaerobic digestion of organic matter	Electricity and heat

Source: Vourdoubas, 2015

4. Impacts of Climate Change on Crete

Climate change, during 2020-2050, is expected to alter the climate conditions causing many changes in many sectors in Crete. Extreme weather events will become more frequent and intense while the average temperature will rise. More hot and dry days and nights will be observed annually while the fire risks will be increased. This increases the probability of having more annual fires in forests and in rural areas. Crete will experience more droughts while the sensitivity in land desertification will be increased particularly in the eastern part of the island. More droughts, higher land desertification and more fires are expected to reduce the biomass potential of agriculture and forest related residues, wastes and by-products. Higher atmospheric CO_2 concentration will increase biomass production in Crete that could partly offset its decrease due to other reasons. Changes in wind velocities, solar irradiance, aerosol concentration in the atmosphere affects the potential for solar-PV and wind electricity as well as for solar heat production. A slight reduction in annual precipitation in Crete will not have serious impacts in water availability and the hydro power potential in the island. More hot days during the summer will increase the need for cooling, particularly in buildings, that results in higher annual electricity demand. Deterioration of climate conditions in the island will change the solar and wind energy potential for heat and power generation. It will also change the biomass and hydro energy potential. Therefore, climate change during the 21^{st} century is expected to change, positively or negatively, island's renewable energies potential.

5. The Potential of Several Renewable Energies in Crete

Island of Crete has abundant renewable energy resources used for heat and power generation (table 2). The annual solar irradiance and the mean annual wind velocities in many areas are high allowing the use of solar and wind energy for heat and electricity generation. The average annual water precipitation in Crete is slightly less than 1 000 mm. However, albeit the attractive geomorphological characteristics of Crete favor hydropower generation there are not many hydroelectric plants operating so far. The biomass potential in Crete is rather high based on agricultural residues, by-products and wastes. Agricultural biomass in Crete is mainly used for heat generation while small quantities of biogas are used for co-generation of heat and power. Low, medium or high enthalpy geothermal fluids have not found so far. The annual solar irradiance in Crete varies in the range of 1 691 KWh/m^2 to 1 821 KWh/m^2 in panels' tilt at 30^o (*Kagarakis, 1987*) while the mean annual water precipitation in the island is estimated at 923 mm (*Tsagarakis et al, 2004*). The annual agriculture-related solid biomass in Crete is estimated at 3 144 tons/capita (*Alatzas et al, 2019*).

6. Impacts of Climate Change on Renewable Energies Potential in Crete

The main renewable energy sources used for heat and power generation in Crete so far are solar energy, wind energy, hydro energy and biomass (table 2). There are not many studies focused on the impacts of climate change in renewable energies potential in Crete while in one publication *Panagea et al, 2014* indicated that the solar-PV electricity generation in Greece will increase in the future by around 4%. The most of the published research indicated that in southern Europe, including Crete, wind energy, biomass and hydro energy potential

will decrease in the future due to climate change. Other studies gave contradictory results. One of them indicated that the wind energy potential in Aegean-sea is not going to decrease while another one predicted that the wind energy generation in Mediterranean-sea is going to decrease by 6-12%. On the contrary, solar-PV potential will increase by 2-10% according to different studies. Regarding hydro energy potential in Crete the most of the studies indicated that it will decrease in the future. Bioenergy potential in the island of Crete is sensitive to climate change due to land desertification and more frequent droughts. Increased forest fires have negative impacts on biomass potential in the island while improved biomass processing technologies in the future will have positive impacts. The main threats of climate change on renewable energies potential in Crete are presented in tables 5, 6, 7 and 8.

Table 5. Main threats of climate change on hydro energy potential in Crete

1.	Changes in rainfall patterns
2.	Flooding and intense rain
3.	Change in air temperature
4.	Various other impacts

Source: Solaun et al, 2019

Table 6. Main threats of climate change on wind energy potential in Crete

1.	Changes in wind speed
2.	Changes in daily or seasonal distribution of wind
3.	Changes in temperature
4.	Sea level rise
5.	Extreme weather events
6.	Increase in atmospheric CO_2 concentration
7.	Others

Source: Solaun et al, 2019

Table 7. Main threats of climate change on solar-PV potential in Crete

1.	Changes in mean temperature
2.	Changes in solar irradiation and cloudiness
3.	Changes in dirt, dust, snow, atmospheric particles and others
4.	Changes in wind speed
5.	Changes in water precipitation
6.	Others

Source: Solaun et al, 2019

Table 8. Main threats of climate change on biomass potential in Crete

1.	Changes in mean temperature
2.	Changes in water precipitation
3.	Changes in atmospheric CO_2 concentration
4.	More frequent droughts and floods
5.	Land desertification
6.	Increase in extreme weather events
7.	Increase in forest fires

Source: Solaun et al, 2019

7. Discussion

The results indicate that climate change during 21st century will alter climate conditions in the

island of Crete, Greece. Their alteration will affect the renewable energies potential for heat and electricity generation. It will alter both negatively and positively the renewable energies potential in Crete affecting the generation of "green energy". Taking into account that in the future de-carbonization of the island's economy is inevitable according to European policies, priorities and targets, regarding climate change mitigation, any changes in renewable energies potential in Crete should be studied and used in the design of new renewable energy plants. Albeit the results from various international studies in the broader neighborhood of southeast Mediterranean basin are somehow contradictory they indicate that the wind energy potential will decrease while the solar energy potential will increase in Crete. Future biomass potential most probably will decrease while the hydro energy potential is expected to decrease slightly. According to other studies (*Lehner et al, 2005*) the hydropower potential in southeastern Europe is going to decrease by at least 25%. Renewable energies generate slightly more than the one fifth of the annual electricity in Crete while generation of "green energy" is going to increase in the future due to EU policies related to climate change mitigation. Our results could be useful in the future design of new renewable energy plants in Crete necessary to comply with EU's climate targets by 2050 taking into account that after the interconnection of the electric grids of Crete and continental Greece, that is going to be completed in the next three years, generation of "green electricity" from the local abundant solar and wind energy resources will be increased in the island. They could be also useful to policy makers who are willing to incentivize and promote various renewable energy technologies. Future research should be focused in more detailed and quantitative estimation of the energy potential of several renewable energies in Crete in the future using appropriate computer simulation models concerning climate change in the specific geographical region.

8. Conclusions

The contribution of renewable energies in energy generation as well as the impacts of climate change on energy potential of various renewable energies in the island of Crete has been studied. Solar and wind energy are mainly used for heat and electricity generation while solid biomass is mainly used for heat production. Small quantities of biogas are used for co-generation of heat and power while the share of hydro energy in electricity generation is very small. Among renewable energies the potential of solar energy, wind energy and agriculture-based biomass in Crete is high while the potential of geothermal energy is low. Renewable energies had a share at 21.20% in total electricity generation in Crete in 2018 while the share of wind energy was at 16.76% and of solar energy at 4.43%. Existing studies focusing on the impacts of climate change on the potential of renewable energies in Crete are rather limited while the results in some of them are contradictory. However, more studies have been published related with the climate change impacts in several EU territories including southeastern Europe and Mediterranean basin. Climate change during 21th century is expected to increase the solar energy potential in Crete by around 4% while the wind energy potential is going to decrease by 6-12%. A slight decrease in annual precipitation in the island is foreseen while the agriculture and forest-related solid biomass potential is expected to decrease due to more frequent forest fires, more droughts and land desertification. However, the rich solar and wind energy resources in Crete that are used for heat and

electricity generation are not going to be affected significantly in the coming decades. Fossil fuels are going to be replaced by carbon-free energy sources, including renewable energies, by 2050 due to climate change mitigation policies. Our results are important for sizing the required renewable energy installations necessary to provide in the future "carbon-free clean energy" in Crete achieving the National, European and international targets for climate change mitigation.

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