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Possibility of Zeroing CO_2 Emissions Due to Energy Use in Gavdos Island, Greece

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Abstract

The possibility of transforming Gavdos Island located south of Crete, Greece to a 100% renewable energies island has been investigated. Gavdos Island has few inhabitants but it hosts a large number of tourists during the summer. Due to the small size of the island the use of vehicles is limited. It has abundant local energy resources, mainly solar and wind energy, which are currently underutilized. Electricity is locally generated with diesel oil and its electric grid is not interconnected with the grid of Crete. Energy demand in the island has been estimated as well as the availability of various renewable energy resources. The most reliable and cost effective of them, including solar thermal, solar and wind power, solid biomass burning and high efficiency heat pumps have been indicated for achieving a 100% renewable island. Electric vehicles must also replace conventional vehicles in order to zero carbon emissions in transport. Since the power grid in the island is isolated, electricity storage is required and it could be obtained either with electric batteries or with a small hydro-pump storage system. The nominal power of the required solar-PV system for covering all the electricity needs in Gavdos island has been estimated at 848 KWp and the required electricity storage capacity was at 19.2 MWh.

Keywords

CO_2 Emissions, Energy, Gavdos Island, Greece, Renewable Energy, Solar Energy

1. Introduction

The severe environmental problems facing humanity including climate change have mobilized the international community who is trying to decrease fossil fuels use and CO_2 emissions in the atmosphere. Current advances in various re-

newable energy technologies have decreased their cost and increased their reliability. Technology innovations and breakthroughs allow their increasing use in heat and power generation as well as in transport.

1.1. Countries Covering All Their Energy Needs with Renewable Energies

Creation of 100% renewable energy systems in various countries and areas has been reported by many authors. The possibility of having 100% renewable energy systems in Denmark by the year 2050 has been reported [1]. The authors considered that the target of 100% renewables combined with energy savings in the country by 2050 could be achievable. For electricity generation the main energy sources foreseen by 2050 are wind energy and biomass, and for heat production biomass, heat pumps and solar thermal systems. In the transport sector they foresee that more electric vehicles and trains will be used. The possibility of creating a 100% renewable energy system for Ireland has been reported [2]. The authors studied various scenarios aiming to cover all the energy needs of the country with renewable energies. In these energy scenarios the main energy source used was biomass followed by wind energy, solar thermal energy, wave and tidal energy. Transportation was fueled by electricity, hydrogen and bio-fuels. The authors highlighted the importance of very efficient energy systems like co-generation of heat and power, heat pumps and district heating. The possibility of achieving 100% electricity supply in Portugal has been reported [3]. The authors stated that the energy system in Portugal in 2006 was dependent on fossil fuels at 86%. However the share of renewables in gross electricity production varies between 20% and 35% depending on hydropower production. A 100% renewable energies scenario is based mainly on hydro and wind energy followed by solar energy and biomass. The main electricity storage foreseen is in pump storage systems followed by hydrogen storage and batteries.

1.2. Islands Covering All Their Energy Needs with Renewable Energies

Transformation of various islands to 100 % renewables has also been reported and implemented. Energy planning in the Croatian island of Mljet with the use of appropriate software has been studied [4]. The authors investigated the possibility of using local renewable energy resources like solar and wind energy combined with hydrogen storage to increase the penetration of renewable energies in the local system. Studying different scenarios, they indicated that decentralized energy generation in Croatian islands could minimize the use of fossil fuels, also reducing their carbon footprint. The increased use of renewable energy resources in the island of Porto Santo in Madeira, Portugal has been reported [5]. The authors investigated the possibility of using indigenous, intermittent renewable energy resources in the island in order to reduce the use of fossil fuels in it. They reported that the island could be transformed to 100% renewable electricity with the use of solar and wind energy. Electricity storage is needed and

they proposed the use of H_2 produced with water electrolysis. H_2 could be used for power generation via fuel cells as well as for transport fuel. The authors stated that reversible hydro and batteries could be used for electricity storage. Higher penetration of renewable energy sources in the island of S. Vicente, Cape Verde has been reported [6]. The island has high wind energy resources and its topography is suitable for using a reverse hydro system for electricity storage. The authors found that wind energy combined with a pump storage system could cover a high percentage of the electricity demand in the island. Wind energy could also be used simultaneously for water desalination covering a large part of the water requirements in the island. A report regarding 35 European smart islands and projects has been published [7]. A smart island is described as an island that creates local sustainable growth, offering a high quality of life to the local people and equipping public power supply and transport systems with the smartest technologies. According to this report there are currently 32 island systems in Greece which are not interconnected to the mainland grid. They are electrified with thermal plants using diesel oil as fuel. The report indicates that in the future solar-PV and wind energy could be used to cover their electricity needs. Renewable energy solutions for islands have been reported [8]. The authors stated, with reference to the programme "Renewislands" that the global development of renewable energy technologies can assure sustainable power supply for islands. To overcome the limitations of intermittent renewable energies, like solar and wind, they proposed the production of H_2 for electricity storage and the use of fuel cells. Electricity generation from renewable energies in small islands has been reported [9]. The author reported that most islands around the world today are dependent on fossil fuels for most of their energy needs, especially for transport and electricity generation. However there are many successful cases of island electrification through renewable energies. Technical and economic analysis of a wind powered pump hydro-storage system in the island of El Hierro, Canary Islands, has been reported by [10]. The authors used an appropriate model to size a wind farm combined with a pump storage system in this island. Their results indicated that the annual wind energy penetration in the electricity grid could be at 68.40%. They also stated that this system was unable to compete economically with the current operating thermoelectric plant.

1.3. Use of Renewable Energy Sources in Greek Islands

The possibility of utilizing renewable energies in Gavdos Island has been reported [11]. The authors stated that a hybrid solar-PV and wind power system could cover all the electricity demand and additionally solar thermal energy and solid biomass would provide all the heat demand. The present status and prospects of RES in Greek islands has been reported by [12]. The author stated various applications of solar and wind energy in Greek islands indicating that hybrid systems with electricity storage in pump hydro systems are suitable for local energy generation in them. Energy statistics and renewable energy potential in

Greece has been reported [13]. The author stated that in December 2014, 84% of the energy generation in non-interconnected islands came from thermal power plants, 13% from wind parks and 3% from PV stations. She also stated that pump storage systems are the cheapest and most convenient way to store electricity. The application of renewable energy resources in the Greek islands of the South Aegean has been reported [14]. The authors stated various applications of renewable energies in this area, concluding that the Hellenic islands of the south Aegean present a high potential for application for renewable energy sources which should be further developed. The sustainable management of renewable energy installations and their impact with reference to the small Greek islands has been reported [15]. The authors stated that small Greek islands constitute sensitive ecosystems and this fact imposes limitations on the development of energy generation plants including renewable energies. A wind power fuel cell hybrid system on the non-interconnected Aegean island grid has been reported [16]. The hybrid system is comprised of a wind turbine, an electrolyzer, a H_2 storage unit and a fuel cell. The authors stated that part of the energy generated by the wind turbine could be stored in the form of H_2 and then it could be delivered for consumption at constant power through the fuel cell. Optimization of the energy production system in the Dodecanese islands, Greece has been presented [17]. The authors investigated the exploitation of renewable energies, particularly solar and wind energy, in the Dodecanese islands having an autonomous electric grid. Examining three different scenarios they estimated the optimum penetration of renewable energies in the electric grid. They concluded that solar-PV could generate 5% of the total electricity needed, wind turbines 40% and thermoelectric plants the remaining 55%, reducing the current electricity cost by 7.6%.

1.4. Energy Consumption and Use of Renewable Energies in Hotels

Energy consumption in Mediterranean island hotels has been reported [18]. The authors stated that in Balearic islands hotels energy consumption varies between 7 up to 77 KWh per night spent (n.s.) with an average of 15.4 KWh/n.s. Similar studies in Greek islands have estimated the energy consumption from 5 to 25 KWh/n.s. with an average at 15.4 KWh/n.s. The possibility of creating zero CO_2 emissions residential houses and hotels due to energy use in Crete has been described [19] and [20]. The author has indicated that the combined use of solar thermal energy, solar-PV energy, solid biomass and ground source heat pumps could result in zero carbon emissions buildings due to energy use in the island. The possibility of increasing the sustainability of small-scale hotels in Greece has been reported [21]. The author suggested that following an energy audit the hotel owner could invest in various sustainable and cost-effective energy technologies which would increase its environmental sustainability, resulting at the same time in financial benefits.

The purpose of this study was to investigate the possibility of zeroing the CO_2 emissions in Gavdos Island due to energy use. Gavdos Island has been chosen

due to its following characteristics:

a) It is a small island with few permanent residents and many tourists during the summer period,
b) Its electric grid is isolated from the grid of Crete,
c) There are abundant renewable energy resources which could be used for electricity and heat generation with reliable and cost effective technologies, and
d) Due to the small size of the island its transformation to a zero CO_2 emissions island is technically easy and economically feasible. It could be used as a demonstration example of a sustainable energy island in Greece.

The current energy consumption in the island has been estimated as well as the fuels used including fossil fuels and renewable energies. Renewable energy technologies which are locally available, mature and cost-effective are reported. Technologies which could be used for covering all its energy needs replacing fossil fuels have been indicated.

2. Gavdos Island

Gavdos is a small island with a surface of 29.6 Km^2 [13] located approximately 58 km south of Crete, Greece (latitude 34˚49'59"North, longitude 24˚04'60"East). Its permanent population is 152 inhabitants [13] who remain there all over the year and its population density is 5.14 inhabitants per Km^2 [13]. It has been estimated that during 2015 approx. 14,000 tourists visited the island. Tourism starts in the beginning of April and ends in the beginning of November. The local economy is based on tourism but the infrastructure in the island is inadequate to host a large number of tourists. Its solar and wind potential is high and its annual solar irradiance is approximately 1900 KWh per m^2 [11].

3. Energy Consumption in Gavdos Island

The small electric grid in the island is non-interconnected with the grid of Crete. In the last few decades various buildings have been constructed for tourist accommodation operating as hotels, apartments and rooms for rent. Various restaurants, tavernas, bars, cafeterias and small mini-markets operate during the summer period in the island, offering the necessary goods and services to visitors. Due to the small size of the island only very few vehicles are currently used for transportation. Energy and fuel consumption in the island includes:

1) Energy consumed in residential buildings and hotels for space heating in the winter and for space cooling in the summer,
2) Energy consumed for hot water production,
3) Electricity consumed for lighting and operation of various electric devices,
4) Energy consumed for cooking, and
5) Fuels used for transportation.

Currently the main energy sources used in Gavdos Island include:

1) Electricity generated from diesel oil and distributed via an electric grid. The electricity generating system in the island is owned by the Public Power Company (P.P.C.),

2) LPG used mainly for cooking,
3) Fuels used in transportation including gasoline and diesel,
4) Solid biomass used for space heating in the winter,
5) Solar thermal energy used for hot water production, and
6) Solar-PV electricity.

Electricity generated with small diesel generators in Gavdos Island during 2015 is presented in Table 1.

4. Possibilities of Using Only Renewable Energy Sources for Covering All the Energy Needs in the Island

4.1. Availability of Renewable Energy Sources in Gavdos Island

Gavdos Island is rich in solar and wind energy. Small quantities of solid biomass are also available in the island. The intermittent nature of solar and wind energy necessitates the use of an electricity storage system. Existing renewable energy sources in Gavdos could be used for:

1) Electricity generation,
2) Space heating and cooling,
3) Hot water production, and
4) Charge of electric batteries which could be used in electric vehicles.

This is presented in Table 2.

In order to use only local renewable energy resources for covering all the energy needs in the island, it is necessary to:

a) Replace the LPG used for cooking with electricity,
b) Use electric cars with batteries instead of conventional cars,

Table 1. Electricity generated with diesel oil in Gavdos Island during 2015.

Month	Electricity generation (KWh/month)	Average electricity generation (KWh/day)
January	38,082	1128
February	35,317	1261
March	39,460	1273
April	42,750	1425
May	44,962	1450
June	62,362	2079
July	85,707	2765
August	91,265	2944
September	72,797	2427
October	66,415	2142
November	38,121	1271
December	40,242	1298
Total	657,480	

Source: P.P.C.

Table 2. Renewable energy sources which could be used in Gavdos Island covering all its energy needs.

	Renewable energy source	Generated energy/use
1.	Solar-thermal energy	Heat/hot water production
2.	Solar-PV energy	Electricity
3.	Wind energy	Electricity
4.	Solid biomass burning	Heat/space heating
5.	Solid biomass burning	Heat/hot water production
6.	Low enthalpy geothermal energy with heat pumps	Heat/space heating
7.	Low enthalpy geothermal energy with heat pumps	Cooling/space cooling
8.	Low enthalpy geothermal energy with heat pumps	Heat/hot water production

Source: Own data.

Table 3. Technologies which could be used for covering all the energy needs in Gavdos Island.

Energy generated/needed	Energy source/technology used
Hot water	Solar thermal-flat plate collectors
Hot water	Solid biomass burning
Hot water	Low enthalpy geothermal energy-heat pumps
Electricity	Solar-PV
Electricity	Wind turbines
Heat for space heating	Solid biomass burning
Heat for space heating	Low enthalpy geothermal energy-heat pumps
Heat for space cooling	Low enthalpy geothermal energy-heat pumps
Electricity for charging electric batteries	Solar-PV
Electricity for charging electric batteries	Wind turbines
Fuels for vehicles	Bio-fuels, bio-ethanol and biodiesel

Source: Own data.

c) Use electric bicycles for transportation or conventional cars using bio-fuels,
d) Use the abundant solar thermal energy for hot water production, and
e) Permanent inhabitants in the island will utilize local biomass or individual heat pumps for space heating in the winter.

The replacement of vehicles using conventional fuels with electric vehicles is currently costly and it could be achieved gradually in few years. Solar thermal energy, solid biomass and heat pumps are currently used in Gavdos.

Renewable energy technologies which could be used for covering all the energy needs in Gavdos Island are presented in Table 3.

The required renewable energy technologies which could be used in Gavdos Island and would result in an island with zero carbon footprints are well proven, mature, reliable and cost-effective. All of them have been used commercially in many cases with good results. However the use of electric cars with batteries in

the island needs consensus among the permanent residents and political will from the local authorities restricting the use of conventional cars from visitors. However this could be achievable under some conditions. Water electrolysis for hydrogen production with the use of solar and wind energy is achievable. Hydrogen could be used either for electricity generation with fuel cells or for transportation with electric cars equipped with fuel cells.

However, since this technology is currently neither mature nor cost-effective, it has not been considered for application in Gavdos Island. This could change though in the near future.

4.2. Preliminary Estimations of the Electricity Required Annually in Gavdos Island in Order to Zero Its CO_2 Emissions

In order to estimate the annual electricity requirements in the island, the following assumptions have been made.

a) Electricity will be used for cooking in residential buildings and in commercial shops, replacing LPG. It will be used also for lighting and the operation of various electric devices,
b) Solar thermal energy will be used for hot water production,
c) Solid biomass will be used for space heating in the residential buildings during the winter,
d) Annual electricity consumption would be at 1000 KWh per permanent inhabitant,
e) Each tourist may remain in the island for five (5) days on average,
f) Each tourist will need 10 KWh per night spent on the island [18],
g) An electric car consumes 0.1 KWh per Km [22]. Annual electricity consumption for transportation in the island would be 5000 KWh, and
h) Although it is not discussed in this paper the implementation of energy efficiency measures in households and enterprises is considered a prerequisite for the zeroing of the carbon footprint in Gavdos Island.

It is considered that these assumptions are realistic and they could be used for the purposes of the current preliminary study.

Therefore the annual electricity consumption by the permanent inhabitants would be 154,000 KWh, for transportation 5000 KWh and from tourists 700,000 KWh, in total 859,000 KWh. Assuming that during the use of diesel oil for electricity generation, 0.27 kg CO_2 per KWh are emitted, it is concluded that the use of a solar-PV system generating all the required electricity in Gavdos Island could result in annual CO_2 savings of 231.9 tons.

5. Preliminary Sizing of a Solar-PV System Generating All the Required Electricity in Gavdos Island

In order to size the necessary solar-PV system which could generate all the required electricity in Gavdos the following assumptions have been made:

1) The monthly electricity consumption will be the same as during the year 2015, as presented in Table 1.

2) The nominal power of the required solar-PV system has been estimated monthly and the larger system is selected.

The calculations are summarized in Table 4.

The necessary nominal power of the PV system in different months varies between 400 to 707 KWp. The larger system is selected and an overdesign of 20% is necessary to cope with extreme conditions. Therefore the required size of the solar-PV system in order to generate all the required electricity in Gavdos island is 848 KWp. Assuming an initial cost of a photovoltaic system at 1500 €/KWp, the total cost of the required solar-PV system is 1,272,000 €. Wind turbines could also be used for electricity generation taking into account the high wind potential in the island. Assuming a load factor at 0.28, the nominal power of a wind turbine generating 859,000 KWh per year is 350 KW. A hybrid system consisting of solar-PVs and wind turbines could also generate the required electricity in Gavdos. The generated power could be distributed in the island with the existing electric grid. However since the grid in the island is not interconnected with the Cretan grid, electricity storage is required. This could be achieved either with batteries or with a small pump storage system. Electricity could also be stored as hydrogen, with electrolysis of water, but this technology is currently rather expensive. The necessary storage capacity of the batteries could be estimated assuming that in extreme conditions electricity will not be generated continuously for 10 days in the winter and for 5 days in summer. Therefore the storage capacity must be 19,200 KWh in order to provide the necessary electricity in extreme conditions. Assuming a battery cost at 200 €/KWh,

Table 4. Sizing of the required solar-PV system which could generate all the required electricity in Gavdos Island.

Month	% of the annual electricity consumption	Monthly consumption (KWh)	Monthly solar radiation in Gavdos[1] (KWh/m^2)	Nominal power of required PV system (KWp)
January	5.90	50,681	106	590
February	5.36	46,042	111	512
March	6.00	51,540	147	433
April	6.49	55,749	158	436
May	6.83	58,670	181	400
June	9.48	81,433	192	524
July	13.03	111,928	205	674
August	13.86	119,058	208	707
September	11.06	95,005	184	637
October	10.09	86,673	155	690
November	5.79	49,736	129	476
December	6.11	52,485	107	606
Total per year	100	859,000	1882	

[1]Source: Own estimations.

the total cost of the required batteries is 3,840,000 €.

6. Benefits in Gavdos Island Due to Its Transformation Into a Zero Carbon Footprint Island Due to Energy Use

The extensive use of various local renewable energy sources in order to cover all its energy needs would result in many environmental, social and economic benefits promoting its attractiveness as a tourism destination. Emissions of CO_2 in the atmosphere would be eliminated due to the use of renewable energies instead of fossil fuels. Energy investments in the island will be increased and regular maintenance of the installed energy systems will be needed. Therefore, employment opportunities for specialized staff will be created. Installation of renewable energy systems will create economic benefits in the small size enterprises and to the households installing these systems. Know-how regarding the transformation of a small Greek island to a zero carbon island, which is currently lacking in Greece, will be acquired. The new know-how could be transferred to other small or bigger Greek islands, multiplying the benefits in the country. The use of different renewable energy technologies in a small area could create an attractive educational pole and students could visit the island for educational purposes attending seminars in the summer. At the same time conferences in the field of renewable energy sources could be organized with study visits in the existing renewable energy systems. The zero carbon footprint of the island would increase its attractiveness to environmentally conscious tourists, increasing their visits to the island and the local income due to tourism.

7. Discussion and Conclusions

The possibility of transforming Gavdos Island to a zero CO_2 emissions island due to energy use has been investigated. Existing studies have indicated that small islands could utilize their indigenous renewable energy sources for covering all their energy needs, avoiding the use of fossil fuels. Gavdos Island has abundant solar and wind energy, which could be used for electricity and heat generation. It also has solid biomass resources which could be used for providing heat during the winter to the local inhabitants. High efficiency heat pumps could be used for providing the required heat and cooling as well. The required renewable energy technologies are reliable, mature and cost-effective. Due to the small size of the island the use of vehicles is limited. In order to avoid CO_2 emissions because of the fuels used, either bio-fuels or electric vehicles could be used. In this case the car batteries could be charged with solar or wind electricity. The electric grid in Gavdos is not interconnected with the grid of Crete. Therefore storage of electricity is required. Taking into account that storage in H_2 is not cost-effective, electric batteries or a small hydro pump system could be used for that. This island could be used as a successful example of a sustainable energy island in Greece, which could be disseminated broadly, since the required renewable energies are locally available and the most of them are reliable and cost effective. Replacement of conventional vehicles with electric vehicles though is

not currently cost effective and it could be subsidized by the government. Transformation of Gavdos in a free CO_2 emissions island due to energy use would result in many environmental, economic and social benefits. The creation of a mathematical model of the energy system in Gavdos and its simulation could give a better understanding of the energy needs in the island and the optimum design of the required renewable energy systems in order to zero its CO_2 emissions.

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