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Creation of Small Rural Energy Communities in the Island of Crete, Greece. Are They Feasible?

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Abstract

Energy communities are well developed in many EU countries allowing the local production of green energy with the participation of environmentally conscious residents willing to be energy self-sufficient utilizing indigenous green energy resources and eliminating their carbon emissions. The possibility of creating energy communities in small rural villages in Crete, Greece has been investigated in the present study. Two small villages in western Crete, Modi and Ravdoucha, have been selected and their annual energy requirements in electricity, domestic hot water and space heating have been calculated. The characteristics of the solar photovoltaic systems generating annually all the electricity demand in these two villages have been estimated. The nominal power of the solar-PV system in Modi village has been evaluated at 334.02 KW_p while the investment cost for each inhabitant in the village at 1,787 €. The corresponding nominal power of the solar-PV system in Ravdoucha village has been evaluated at 370.86 KW_p and the corresponding cost for each inhabitant at 3,617 €. The solar photovoltaic system in each village can be created collectively with the establishment of an energy cooperative and the active participation of all the residents. Additionally, it has been indicated that the annual demand for domestic hot water and space heating in these two villages can be covered individually using their indigenous carbon-free green energy resources. Therefore, the creation of small energy communities in small rural villages in Crete is technically and financially feasible. The results of the present study can be used by policy makers and local authorities in Crete willing to promote the green energy transition in small rural societies.

Keywords: Crete; energy communities; green energy transition; procumers; renewable energies; rural villages.

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1. Introduction

The possibility of creating energy communities in small rural villages in Crete, Greece has been studied. Energy communities are well developed in many European countries [1, 2, 3, 4]. They are established with the participation of local societies facilitating their green energy transition using indigenous benign energy resources resulting in economic benefits to energy-responsible citizens. Rural societies can establish local energy communities exploiting their rich solar energy and biomass resources generating heat and electricity [1, 5]. The investment cost per inhabitant in a collective solar-PV system is lower than the investment cost of individual solar-PV systems in each building [1]. Use of locally available renewable energies instead of fossil fuels can eliminate the carbon emissions and facilitate the green energy transition. Creation of energy communities is currently supported with several incentives by the Greek government [6] while there is an extensive network of energy cooperatives in Europe [7].

The aim of the current work is the investigation of the possibility of creating energy communities in two small villages in Crete, Greece using their indigenous renewable energy resources and the estimation of various characteristics of the collective solar photovoltaic systems.

The text is structured as follows: After the literature review the availability of renewable energies in Crete and the power system in the island are described. Next, the existing energy communities in Crete and the characteristics of the villages Modi and Ravdoucha located in western Crete are mentioned. The investigation of the possibility of creating energy communities in these two villages as well as the establishment of citizen-driven small renewable energy projects in Crete are examined in the following sections. The text ends with the presentation of the benefits resulted from the establishment of rural energy communities in Crete, the discussion of the findings, the conclusions drawn and the citation of the references used. Although the solar and wind energy potential in the island is high there is limited research regarding the development of energy cooperatives in Crete. The current study contributes in the existing knowledge regarding the establishment of small rural energy communities which are not well developed so far in Greece. It can be useful to local municipalities and to local authorities, to policy makers and to energy conscious citizens who are willing to collectively participate in the green energy transition of their local societies. The accuracy of our estimations depends on our assumptions regarding the number of local inhabitants and the existing tourism facilities in the abovementioned villages. Additionally, on our assumptions regarding the number of households, the residential buildings and the vehicles in these two villages as well as on the average annual energy consumption in households and in tourism facilities.

2. Literature Review

The authors in [8] have studied the implications of developing community energy and decentralized electricity systems in UK. They stated that civil society actors could deliver 50% of the final electricity demand from de-centralized low-carbon energy sources by 2050. They also mentioned that such a radical transition will require both institutional and technological change regarding energy governance, community business models and new financial and organizational structures. The authors in [9] have examined the collective ownership in renewable energy projects combined with sustainable de-growth. They stated that small-scale technology and decentralized ownership in the field of energy are commonly regarded as potential precursors of a sustainable de-growth society. They also mentioned that collective and political motivated renewable energy projects can be conceived as de-growth initiatives combined with social movements. The authors in [7] have studied the role of European renewable energy cooperative network. They stated that initial legitimacy deficits inherent in hybrid organizations can be overcome and even transformed into an institutionalization opportunity through an inter-organizational network like the energy cooperatives. The authors in [10] have investigated the social energy systems to community renewable energy projects in the global south. They stated that rural community energy projects in the global south usually follow the top-down approach without helping the reduction of energy poverty and the improvement of livelihoods. They also mentioned that community energy projects are related with many good practices comprising: inclusion of multiple stakeholders, capacity building, affordability, maintenance, demonstrations, dissemination and education practices, local manufacturing and training centers, development of symbiotic services et cetera. The authors in [2] have studied the energy commons and their impact on green energy transition. They stated that integrated community energy systems can facilitate the transition towards socially inclusive, environmentally-friendly energy systems and to support the local economy. The authors in [11] have examined the contribution of citizen-driven renewable energy projects in the promotion of the green energy transition. They stated that the development of community energy projects consists of a social innovation. They also mentioned that there are four criteria characterizing the social innovation in local collective energy projects including: a) cities and opportunities, b) the agency of civil society, c) reconfiguration of social practices, institutions and networks, and d) new ways of working. The author in [12] has studied a prototype business model for renewable energy communities. He stated the "consumer stock ownership plan" consists of an attractive business model for renewable energy communities. He also mentioned that a low-threshold financing method allows to individuals, particularly to low-income households to invest in renewable energy projects. This also facilitates co-investments by municipalities, SMEs, plant engineers and energy suppliers. The authors in [3] have examined the role and responsibility of citizens in the transition to sustainable energy systems. They proposed the concept of "energy citizenship" redefining the rights and duties of citizens regarding the energy production and consumption in local societies. The authors in [13] have studied the potential of peer-to-peer electricity trading among prosumers in the local energy market in Netherlands. Electricity trading is related with environmental, economic, social and technological parameters while prosumers value the environmental dimension first. They mentioned that many prosumers are willing to offer free electricity to energy poor households. The authors in [14] have reviewed the community-based energy systems which consist of promising models facilitating the green energy transition. They stated that energy communities are related to a place while they are primarily focused on meeting the economic objectives of their members than their social and political goals. The authors in [1] have studied the profitability of solar-PV sharing in energy communities. They stated that the installation of optimal-sized solar-PV systems in energy communities is more profitable compared to individual installation in buildings. They also mentioned that if the load profiles of the consumers differ significantly the cost saving and the profitability are higher. The author in [15] has described and assessed a small renewable energy community in the island of Crete, Greece. The energy community that included residential buildings and agricultural activities was located in a Cretan village while it was covering all its energy demand with solar energy and solid biomass. The author in [16] has studied the energy consumption and the use of renewable energy technologies in hotels located in the island of Crete, Greece. He stated that energy analysis in five summer operating hotels in Crete, Greece has indicated that their annual energy consumption was at 149 KWh/m^2 or 19.4 KWh per night spent (p.n.s.). He also mentioned that their average carbon emissions due to energy use have been estimated at 12.1 kgCO_2/p.n.s. The author in [17] has examined the creation of net-zero carbon emission residential buildings due to energy use in Crete, Greece. He stated that solar-thermal energy, solar-PV energy, solid biomass and heat pumps can cover all the energy requirements of residential buildings eliminating the use of fossil fuels and their carbon emissions. The authors in [18] have studied the energy communities in the transition to a low-carbon future. They stated that the term "energy communities" often denotes different things which require clarification. They also mentioned that energy communities might be "place-based" or not. Additionally, they can be either "single-purpose" or "multi-purpose" communities. The authors in [4] have examined the value of local electricity among German residential customers. They stated that local energy markets can balance generation and demand at distribution network level. They also mentioned that economic parameters are most important in German households for their participation in local energy markets. The authors in [19] have analyzed the social acceptance of renewable energy projects in western Greece. They analyzed questionnaires from over 200 local households. They stated that the willingness to pay for hypothetical renewable energy projects in western Greece is associated with age, family size, income and awareness on renewable energies. The authors in [20] have studied the community financing and the characteristics of potential investors in renewable energy projects in Austria and Switzerland. They stated that from a large sample of 2,260 respondents in Switzerland and Austria the majority would be willing to invest 1,000 to 10,000 euros in small projects. They also mentioned that potential investors in Austria are male homeowners with higher incomes while the Swiss investors are more educated. The authors in [21] have studied a sustainable community in China which has created a micro-energy grid. They stated that micro-energy grids enable to share various local renewable energy sources generating heat and electricity. They also mentioned that a community in China adopting micro-energy grids can achieve 26% carbon emissions reduction and 25% energy consumption savings compared to conventional building energy systems. The authors in [22] have investigated the key success factors for global application of local micro-energy grids. They stated that local micro-grids can be either autonomous or part of a macro-energy grid. They also mentioned that the parameters affecting the feasibility of local energy micro-grids include: energy tariffs, state financial support, local climate, local availability of benign energy sources, governmental energy policies etc. The authors in [23] have studied the snowball effect of energy communities. They stated that energy communities might have a snowball effect on grid tariffs. They also mentioned that the grid tariff structure which is chosen by the grid operator has an important role regarding the energy investments of the energy community and the gains achieved among its members. The author in [24] has studied the barriers and the incentives for community energy production and use. He stated that community energy projects involve many complexities and have various barriers while frequently several countries offer financial support to promote them. The authors in [25] have analyzed the factors affecting a shift in a local energy system towards 100% renewable energy community. They stated that the political and policy conditions in Germany are such that the development of renewable energy technologies are encouraged. They also highlighted the important role of participation of local societies, their contribution in the local energy system, their sense of ownership as well as the role of mayor as a policy entrepreneur. The authors in [26] have reviewed the social arrangements, the technical designs and the impacts of energy communities. They stated that energy communities enable consumers to jointly pursue their individual and collective economic, environmental and social goals contributing in the decarbonization of the energy system. They also mentioned that the different actors involved in local energy projects and in the technical design of local energy systems have important impacts on energy communities. The authors in [5] have studied the nexus of rules, social capital and cooperation in the development of bioenergy villages in Germany. They, based on two case studies in Germany, stated that the promotion of social capital, the trust among local actors as well as their involvement in social activities and in sharing information contributes in the development of local sustainable energy communities. The Greek law No 4513/2018 in [6] introduced the concept of energy communities in the country. Energy communities are expected to promote the development of renewable energy technologies at local level while they are eligible for governmental financial support. A repository of energy communities [27] have been created in 2022 in EU to assist local actors and citizens willing to set-up a citizens' energy community or a renewable energy community through technical and administrative advice. The authors in [28] have studied the interconnection of the autonomous electric grid of Crete with the electric grid of continental Greece with two undersea electric cables. They stated that the interconnection is taking place in two phases as follows: Phase I: Crete – Peloponnese with 150kV AC interconnection, 2×200MVA (~2x140MW) capability, and Phase II: Crete - Attica with DC interconnection, 2×350MW capability. The characteristics of the autonomous power system of Crete in 2018 have been described in [29]. The activities and the investments of Minoan energy community operating successfully in the island of Crete have been presented [30]. The authors in [31] have studied the opportunities of community energy projects in UK and the barriers they face. They stated that community renewable energies have played a significant role in the green transition of the UK's energy system. They also mentioned that recent changes in governmental policies have discouraged the further development of community solar photovoltaics schemes in UK. The authors in [32] have reviewed the community energy research. They stated that community energy research has been taken-off only very recently. They also mentioned that there are many active networks in community energy particularly in developed countries but there is limited knowledge exchange among these networks. The authors in [33] have studied the social acceptance of local renewable energy communities in Italy, Switzerland, Austria and Germany. They stated that solar farms have high acceptance in local societies while wind farms have an ambiguous effect. The authors in [34] have implemented an empirical study regarding the community energy participation and attitudes to renewable energy. They examined the attitudes of the members in two energy cooperatives in Belgium regarding on-shore wind energy and citizens who were not members in energy cooperatives. The authors stated that cooperative members have significantly more positive attitudes towards renewable energies than non-members. Existing literature indicates that energy communities are well developed in several EU countries based on local renewable energy resources covering the energy demand of households and enterprises and selling any surplus into the grid. These energy communities are non-profit organizations having social and environmental targets related with climate change mitigation and the required green energy transition at local level while their members have also a small economic benefit. The energy cooperatives co-exist with private and public power generation companies being part of the social sector of the economy. Their growth has been accelerated due to the development of several low- or zero-carbon emission energy technologies which are profitable compared to conventional energy technologies based on fossil fuels and the global commitment for de-carbonization of the economy in the coming decades.

3. Renewable energy resources in the island of Crete, Greece

The island of Crete, Greece is rich in renewable energy resources. The potential of solar and wind energy is high allowing their use for heat and power generation. The solid biomass resources are also high based mainly on olive tree by-products and residues. Other biomass resources based on forest residues, by-products and residues of other trees like orange trees and vineyards are also available. Small quantities of biogas are also produced from various organic wastes. However, the potential of hydroelectric energy as well as of geothermal energy in the island is low. Solar energy, wind energy and solid biomass are currently used for energy generation in Crete. Solar thermal energy and solid biomass are used for heat production while solar and wind energy are used for electricity generation. Ambient heat is used with high efficiency heat pumps for heat and cooling production. Apart from heat and power generation agricultural raw materials are not used in Crete for the production of vehicles' fuels. The renewable energy sources which are currently used for energy generation in the island are presented in table 1.

Table 1: Renewable energy sources which are currently used for energy generation in Crete.

Renewable energy source	Technology used	Generated energy	Applications in Crete
Solar energy	Flat-plate solar collectors	Heat	Production of domestic hot water
Solar energy	Solar photovoltaic panels	Electricity	Several applications in various sectors (buildings, industry, electric grid, charging the batteries of electric vehicles et cetera)
Wind energy	Wind turbines	Electricity	Electricity generation for the grid
Hydroelectric energy	Hydroelectric turbines	Electricity	Two very small plants operate in Crete generating electricity for the grid
Solid biomass	Burning	Heat	Several applications in buildings, in industry and in agriculture
Biogas	Burning	Heat and Electricity	Only few small plants operate in Crete
Ambient heat	Heat pumps	Heat and cooling	Many applications in buildings and in industry

Source: own estimations

4. The power system in Crete

The power system of Crete was autonomous for many years. However, the interconnection of its electric grid with the grid of continental Greece with two undersea electric cables is currently taking place and hopefully the interconnection will be finalized by 2024. The capacity and the characteristics of the two electric cables are: a) Interconnection of western Crete with Peloponnese with 150kV AC, 2×200MVA (~2x140MW) capability, and b) Interconnection of Heraklion with Attica with DC, 2×350MW capability [28]. Electricity was generated so far in Crete from three thermal power stations located in the prefectures of Chania, Heraklion and Lasithi using fuel oil and diesel oil. Additionally, electricity was generated with wind parks, solar-PV systems and with two very small hydroelectric plants [29]. The share of electricity generated by renewable energies in the electricity mix in Crete was in 2018 at 21.20%. The characteristics of the autonomous electric system of Crete in 2018 are presented in table 2.

Table 2: Characteristics of the autonomous electric system of Crete (2018).

Parameter	Value	%, of total
Total annual electricity generation	3,043 GWh	
Total installed power (oil and renewable energy power stations)	1,120.9 MW	
Maximum annual power demand	684.6 MW	
Installed power of hydropower plants	0.6 MW	0.05
Installed power of solar-PV plants	95.5 MW_p	8.52
Installed power of wind farms	200.3 MW	17.87
Total installed power of renewable energy systems	296.4 MW	26.44
Installed power of thermal power stations based on oil	824.5 MW	73.56
Annual electricity generation from hydropower plants	0.257 GWh	0.01
Annual electricity generation from solar-PV plants	134.8 GWh	4.43
Annual electricity generation from wind farms	510.1 GWh	16.76
Total annual electricity generation from renewable energy systems	645.2 GWh	21.20
Total annual electricity generation from oil	2,397.8 GWh	78.80

Source: [29]

5. Energy communities in the island of Crete

The first energy community in Crete as well as in the whole insular area in Greece is Minoan energy community based in the village Arkalochori, Heraklion Prefecture, Crete, Greece [30]. The concept of energy communities (or energy cooperatives) is already well established in many EU countries where many energy communities currently operate with the participation of thousands of citizens. The most of them generate electricity from several local renewable energy sources including solar energy, wind energy, hydroelectric energy, solid biomass, biogas et cetera [1, 5]. Participation in energy communities allows to citizens to become “procumers” generating the electricity that they self-consume and selling any surplus into the grid. They also reduce the energy-related carbon emissions locally while they benefit from the local installation of energy systems using the indigenous green energy resources. Minoan energy community, with more than 250 members, has already installed two solar-PV parks in the Prefecture of Heraklion, Crete. The nominal power of the first is at 405 KW_p while of the second at 999.54 KW_p. Additionally, Minoan energy community is planning to develop more solar-PV parks in Crete while it is also interested to invest in pumped-hydro storage plants as well as in a solar-thermal power station in the island. Apart from Minoan energy community there are not any other energy communities, with many participants, operating currently in the island of Crete, Greece. Several efforts, without success though, have been made in the past for the establishment of energy communities with broad participation of the local societies in Crete.

6. The villages Modi and Ravdoucha in Western Crete

Our case studies are related with two small villages, Modi and Ravdoucha, located in western Crete in the municipality of Platanias, Prefecture of Chania.

Modi village is located around 15 Km west of the city of Chania. Its permanent inhabitants are 243 while there are few tourism accommodation facilities with capacity at around 30 beds. Modi is surrounded by green nature and olive groves while it is a fertile area and most villagers live of agriculture. Beside the olive trees and the vegetables, there is also a lot of wild grow like pine trees, plane trees, cypresses and eucalyptus trees. Fields of orange trees and vines alternate with unspoiled nature, a variety of plants and shrubs.

Ravdoucha village is one of the most beautiful and traditional places in Rodopos Peninsula, located 21 Km west of Chania, West Crete. The small village, with 133 permanent inhabitants, is located on a hill with a memorable view, overlooking the gulf of Kissamos-Kastelli and also is very close to the beach.

The landscape of the area is glorious, with steep mountains, wild rocks, and terraced olive groves. There are a few low- capacity hotels and some touristic villas with private pools at Ravdoucha. The capacity of the tourism accommodation facilities is estimated at around 150 beds. The typical annual energy use in a residential building in Crete is presented in table 3.

Table 3: Typical annual energy use in a residential building in Crete, Greece.

Sector	Energy use (%)	Energy use (KWh/m^2 year)
Space heating	63	107.1
Domestic hot water production	9	15.3
Lighting	12	20.4
Operation of various appliances including heat pumps	16	27.2
Total	100	170

Source:[17]

For the estimation of the annual energy requirements in the two villages the following assumptions have been made:

a) Each residential building in these villages hosts four people while its covered area is at 120 m^2,
b) The owners of each residential building have one electric vehicle with re- chargeable batteries covering 5,000 Km annually,
c) The energy consumption per sector in each residential building is similar with the consumption presented in table 3,
d) The electricity consumption of the electric vehicles owned by local residents is at 0.2 KWh/Km,
e) The tourism facilities operate 100 days per year while their energy consumption is at 19.4 KWh/p.n.s. [16]. Tourism facilities use grid electricity for covering all their energy needs,
f) There are no industrial activities in these two rural villages,
g) The annual solar photovoltaic electricity generation is at 1,400 KWh/KW_p. The investment cost of the solar-PV system is at 1,300 €/KW_p,
h) The electricity needs in both villages are currently covered with grid electricity. The needs for space heating are currently covered by locally produced solid biomass, oil and grid electricity. The needs for domestic hot water are covered with grid electricity and solar energy.

6.1 Annual energy requirements in Modi village

According to the abovementioned assumptions the total number of residential buildings in Modi village is 61 while there are 61 electric vehicles owned by local residents with re-chargeable batteries. The visitors spent 3,000 bed nights per year in the village. The energy consumption in residential buildings, in tourism facilities and in electric vehicles are presented in table 4.

Table 4: Estimation of annual energy consumption in Modi village, Crete.

Number of residential buildings	61
Covered surface of residential buildings	7,320 m^2
Total annual energy consumption in residential buildings	1,244,400 KWh/year
Annual electricity consumption in residential buildings	348,432 KWh/year
Annual energy consumption in residential buildings for space heating	783,972 KWh/year
Annual energy consumption in residential buildings for domestic hot water production	111,996 KWh/year
Annual heat consumption in residential buildings	895,968 KWh/year
Number of beds in tourist accommodations	30
Average occupancy in all tourism facilities	3,000 nights spent
Annual electricity consumption in tourism facilities	58,200 KWh/year
Number of electric vehicles	61
Total number of Km per year travelled by each electric vehicle	5,000 Km/year
Total number of Km per year travelled by all electric vehicles	305,000 Km/year
Total annual electricity consumption in electric vehicles	61,000 KWh/year
Total annual electricity consumption in Modi	467,632 KWh/year
Total annual energy consumption in Modi including heat and electricity	1,363,600 KWh/year

Source: own estimations

6.2 Annual energy requirements in Ravdoucha village

Table 5: Estimation of annual energy consumption in Ravdoucha village, Crete.

Number of residential buildings	34
Covered surface of residential buildings	4,080 m^2
Total annual energy consumption in residential buildings	693,600 KWh/year
Annual electricity consumption in residential buildings	194,208 KWh/year
Annual energy consumption in residential buildings for space heating	436,968 KWh/year
Annual energy consumption in residential buildings for domestic hot water production	62,424 KWh/year
Annual heat consumption in residential buildings	499,392 KWh/year
Number of beds in tourist accommodations	30
Average occupancy in all tourism facilities	15,000 nights spent
Annual electricity consumption in tourism facilities	291,000 KWh/year
Number of electric vehicles	34
Total number of Km per year travelled by each electric vehicle	5,000 Km/year
Total number of Km per year travelled by all electric vehicles	170,000 Km/year
Total annual electricity consumption in electric vehicles	34,000 KWh/year
Total annual electricity consumption in Ravdoucha	519,208 KWh/year
Total annual energy consumption in Ravdoucha including heat and electricity	1,018,600 KWh/year

Source: own estimations

According to the abovementioned assumptions the total number of residential buildings in Ravdoucha village is 34 while there are 34 electric vehicles owned by local residents with re-chargeable batteries. The visitors spent 15,000 bed nights per year in the village. The energy consumption in residential buildings, in tourism facilities and in electric vehicles are presented in table 5.

7. Possibility of creating energy communities in Modi and Ravdoucha village eliminating the use of fossil fuels and the carbon emissions

The fossil fuels used for heat and electricity generation in Modi village can be replaced with locally available renewable energy sources including solar energy, solid biomass and ambient heat. This can be achieved as follows:

a) The grid electricity used can be replaced with solar-PV electricity. Electricity is consumed in residential buildings, in tourism facilities and for re-charging the batteries of the electric vehicles in the village,
b) The space heating in the buildings can be achieved with locally produced biomass or/and with high efficiency heat pumps, and
c) The production of domestic hot water in the residential buildings can be produced with solar thermal energy or/and with solid biomass.

Solar-PV electricity can be generated in Ravdoucha village collectively from an energy community with the active participation of the local residents.

They will finance the solar energy investment which can be installed in a location nearby the village becoming "*procumers*" generating the electricity that they consume. Any solar electricity that will not be consumed locally will be sold into the grid.

Taking into account the abovementioned assumptions for the annual generation of 519,208 KWh/year which are needed in Ravdoucha village the nominal power of the solar-PV system generating the required electricity is estimated at 370.86 KW_p while its investment cost at around 481,118 €. The investment cost corresponds at 3,617 € per inhabitant.

Similarly, for the annual generation of 467,632 KWh/year required in Modi village the nominal power of the solar-PV system is at 334.02 KW_p while its investment cost is at around 434,230 € corresponding at 1,787 € per inhabitant.

The space heating of the residential buildings can be achieved individually preferably with olive tree-related solid biomass produced locally in both villages. The production of domestic hot water can be also achieved individually with the well-known, broadly used and cost-effective solar thermal heaters with flat plate collectors combined with solid biomass during the winter months. The characteristics of the solar photovoltaic systems which can generate all the electricity required annually in both villages are presented in table 6.

Table 6: Characteristics of the solar photovoltaic systems which can generate all the electricity required annually in Modi and Ravdoucha villages, Crete.

Parameter	Modi	Ravdoucha
Nominal power of the solar-PV system	334.02 KW_p	370.86 KW_p
Annual electricity generation	467,632 KWh/year	519,208 KWh/year
Investment cost of the solar-PV system	434,230 €	481,118 €
Permanent residents	243	133
Investment cost of the solar-PV system per inhabitant	1,787 € per inhabitant	3,617 € per inhabitant

Source: own estimations

The green energy technologies which can be used for heat and electricity production covering all the annual energy requirements in the two rural villages in Crete are presented in table 7.

Table 7: Green energy technologies which can be used for heat and electricity generation covering all the annual energy requirements in the two rural villages in Crete.

Energy source/Technology	Local availability	Energy produced	Energy needs that can be covered	Carbon emissions
Solar energy/ solar thermal systems	Yes	Heat,	Domestic hot water production in residential buildings and in tourism facilities	No
Solar energy/solar photovoltaic systems	Yes	Electricity	Electricity used in residential buildings, in tourism facilities and for re-charging the batteries of electric vehicles	No
Solid biomass/burning	Yes	Heat	Space heating in residential buildings and domestic hot water production	Yes, (net zero -carbon emissions)
Ambient heat/High efficiency heat pumps	Yes	Heat and cooling	Space heating and cooling in residential buildings, in tourism facilities and for domestic hot water production	No

Source: own estimations

8. The establishment of local energy communities in small rural villages in Crete

A local energy community can be created in each of the abovementioned small rural villages in Crete. All the local residents should be involved in the investment of a solar-PV system generating collectively the required electricity in community's residential buildings, in tourism facilities and in re-charging the batteries of the electric vehicles of the local inhabitants. Participation of public stakeholders including the local municipality is desired. Participation of private stakeholders like the owners of tourism facilities in the villages is also helpful. The installation of a collective solar-PV system generating all the annual electricity demand in the two villages is cost-effective and has many economic benefits compared to the installation of individual solar-PV systems by each inhabitant willing to eliminate the use of fossil fuels and the carbon emissions in his property [1]. Solar photovoltaic systems have high local acceptance in community energy projects compared to other green energy technologies [33]. Additionally, the government offers many financial and non-financial incentives promoting the establishment of energy communities in Greece. The energy community should also invest in a collective system used for re-charging the batteries of the electric vehicles owned by the local residents with solar electricity. The majority of the local residents willing to eliminate their carbon footprint and to promote the necessary green energy transition in their local societies should actively participate in these energy communities. They should be involved in all the decisions taken regarding the technology use, the financing options and in any other decisions taken about its operation and its future development. The local residents should be responsible for the heating and the domestic hot water production in their residential buildings. The owners of the tourism facilities in the two villages should have the option to participate in the energy communities generating the electricity required annually in their accommodations. The estimated cost per capita regarding the investment capital in the common solar-PV system is not prohibitory for the local residents indicating that project financing is not a barrier for the establishment of local energy communities.

9. Benefits from the creation of rural energy communities in Crete, Greece

The establishment of small energy communities in the two abovementioned villages in Crete, Greece is going to facilitate the green energy transition in small rural communities in accordance to national and EU policies for realizing carbon-free societies in the next decades. It indicates the commitment of the local inhabitants to these policies achieving economic, environmental and social benefits. The local energy community can be supported by the existing network of energy cooperatives in EU and from the incentives offered by the Greek government. A low-threshold financing for membership in the local energy communities is inclusive and is not discouraging the participation of the low-income households. It can help energy poor households in the villages, increasing social cohesion, offering either free or low-cost electricity to them. The local green energy investments will be beneficial in the local economy. The realization of small energy communities requires the development of new business models and new financial and organizational structures which are innovative and unusual so far in small rural societies in Greece. They will enhance the social bonds increasing the cooperation among the local residents. The possibility of covering all the demand for space heating and for domestic hot water production, in a cost-effective way, facilitates the transition to net-zero carbon emissions local societies. The main barrier for the creation of small green rural energy communities in Crete is related with the acceptance of the concept of a local energy community from the residents and the difficulties related with its implementation which though results in economic, environmental and social benefits. It is alco related with the acceptance of the necessity to be self-sufficient in electricity generation, avoiding the use of carbon-related grid electricity, and the necessity to eliminate the net-carbon emissions in their local societies.

10. Discussion

Our results indicate that small energy communities can be created in the villages Modi and Ravdoucha with 243 and 133 inhabitants correspondingly located in western Crete, Greece. The main activity in these two villages is agriculture while there are also tourism facilities hosting a small number of visitors during the summer. The annual solar irradiance is high facilitating the use of solar energy technologies for heat and power generation. It was found that solar-PV systems can cover all the annual electricity demand in residential buildings, in tourism facilities and for re-charging the batteries of electric cars of the residents in both villages. The results also indicate that the investment cost per permanent resident for the installation of the solar-PV system is low and affordable. Additionally, solar energy and the local biomass resources combined with heat pumps can cover all the heat energy demand in these two villages eliminating all the carbon emissions due to heat and electricity consumption. The current study indicates that energy communities can be established in rural villages in Crete which using the indigenous renewable energy resources in a cost-effective way can eliminate the use of fossil fuels and their carbon emissions achieving the green energy transition locally. Although the island of Crete has abundant solar energy resources which can be used for the development of energy communities it is lagging behind compared to other European countries who have established large and profitable energy communities with the participation of thousands of citizens/procumers. Creation of small rural energy communities in Crete is a multidimensional problem having not only economic aspects but also social, environmental and political. Apart from achieving an economic benefit the sensitization of the local residents and their commitment regarding the elimination of the carbon footprint is also important. Our results do not indicate whether the local residents will be eager to participate in the realization of local energy communities or if they are willing to promote the green energy transition in their communities. The accuracy of our estimations depends on the accuracy of the data used and the assumptions made regarding the number of residents, the number of tourism facilities and the number of the electric vehicles in these two villages. Future research, with proper questionnaires, should be focused in the investigation of the willingness of the local residents in these two rural communities to participate actively in the creation of local energy cooperatives.

11. Conclusions

The establishment of energy communities in small rural villages in the island of Crete, Greece has been examined. Renewable energies including solar energy, wind energy and solid biomass are abundant in Crete and they are already used for heat and power generation. Small rural villages can collectively exploit their local green energy resources generating the energy required for covering their annual heat and electricity demand. The Greek government supports the creation of energy communities while there are many good and successful examples related with energy cooperatives in several EU countries. The current research has indicated that small energy communities can be created in the villages Modi and Ravdoucha located in western Crete using the abundant solar energy generating solar electricity. Solar photovoltaic systems can generate all the electricity required annually in these two villages covering the power demand in residential buildings, in tourism facilities and for re-charging the batteries of the electric vehicles owned by the local residents. The nominal power of the solar-PV system in Modi village has been calculated at 334.02 KW_p while the investment cost for each permanent resident at 1,787 €. The corresponding nominal power of the solar-PV system for Ravdoucha village has been calculated at 370.86 KW_p and the corresponding cost at 3,617 €. Additionally, the use of solar thermal energy, locally produced solid biomass and heat pumps can cover all the annual heating demand in these two villages eliminating the use of fossil fuels and the carbon emissions achieving their green energy transition. The current study indicates that the establishment of local energy communities, using the indigenous green energy resources, in rural villages in Crete is technically feasible while the investment cost for each resident is affordable. This fact combined with the governmental support and the technical and administrative assistance offered from the existing networks of energy cooperatives in EU indicates that the creation of energy communities in small villages in Crete can be achieved without major technical and financial difficulties.

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