ECOLOGICAL TOURISM: AN INNOVATIVE STAND-ALONE PV/HYBRID COMMERCIAL INSTALLATION IN GREECE FOR THE ELECTRIFICATION OF A COMPLEX OF TWELVE BUNGALOWS

C Protogeropoulos
CRES, Centre for Renewable Energy Sources
19th km Marathonos Av., 190 09 Pikermi, Athens, Greece
Tel: +30 1 6039900, FAX: +30 1 6039905, e-mail: cprotog@cres.gr

M Soursos
SENERS Ltd
16, Kleovoulou Str., 117 44, Athens, Greece
Tel: +30 1 9270940, FAX: +30 1 9270857

ABSTRACT: This paper reports on the design, installation and operational experiences of an innovative autonomous hybrid PV/diesel system of a bungalow complex in Elounda, Crete. The economical and technical factors are examined and the social dimension of RES installations in tourists resorts is analysed. A scenario for the implementation of PVs in the islands of the Aegean Sea is proposed, taking into account the existing energy supply status quo and environmental factors. A new market for PV and combined renewable systems seems to emerge in the vast market of ecological tourism with benefits for all the involved parties, i.e. the owners, the operators, the users, the tourists, the investors, the utilities, the renewable systems industry, the local authorities etc.
Keywords: Ecological Tourism - 1: Energy Options - 2: Stand-alone PV Systems - 3

1. INTRODUCTION

In the last decade, the development of the tourist industry was substantial on the international level, [1], and tourism today is one of the largest commercial sections in the world. The objectives of ecological tourism refer to:

- treatment of solid and fluid wastes
- prevention of air, sea water and soil pollution
- quality of drinking water
- restrain of mechanical noise
- minimisation of power generation by fossil fuels
- rational use of electrical and thermal loads
- avoidance of aerial power transmission and distribution lines
- aesthetical architectural adoption of a tourist facility within the local micro-environmental particularities

Photovoltaic systems are technologically mature and provide a reliable solution for electricity supply in existing or in planned tourist resorts at places without electrical grid.

The case of a bungalow complex in the tourist resort at Elounda, Crete, will be examined in this paper. The ecological character of this tourist facility is due to the replacement of the old diesel engines by a stand-alone PV system to cover the electrical demand. It will be seen that in the tourism sector, the high capital cost of PV systems is not a restraint and a market widening could be achieved in Greece under a well-structured promotion programme. From the technical point of view, an optimum PV system design is feasible as the peak demand in the tourist period in Greece coincides with the maximum solar insolation period.

2. THE TOURIST FACILITY AT ELOUNDA

2.1 General

The photovoltaic system at Elounda is the first autonomous PV installation in Greece for the electrification of a tourist resort. The tourist facility was established in 1978 in Crete and the bungalow complex consists of 12 individual villas and one restaurant. Bioclimatic design of the buildings was undertaken and, in this way, summer interior comfort and energy savings were achieved. A general view of the Elounda system is seen in Figure 1.

Figure 1. The Elounda tourist facility and PV system

The PV system was installed in June 1996 and operates satisfactorily since then. Until last summer, the electrical demand was covered by two diesel generators which consumed approximately 18tn of light diesel fuel between May and September in a typical tourist season. The expenses for fuel and regular engine maintenance exceeded 13kECU in the 1995 tourist season. The environment was also burdened from emissions and noise pollution. Grid connection was not economically feasible due to the archaeological character of the site and the associated extreme expenses required for underground cabling. Solar photovoltaics were therefore implemented to cover the electrical demand of the tourist resort.

2.2 Technical Design

The stand-alone PV system at Elounda is presented in Figure 2.

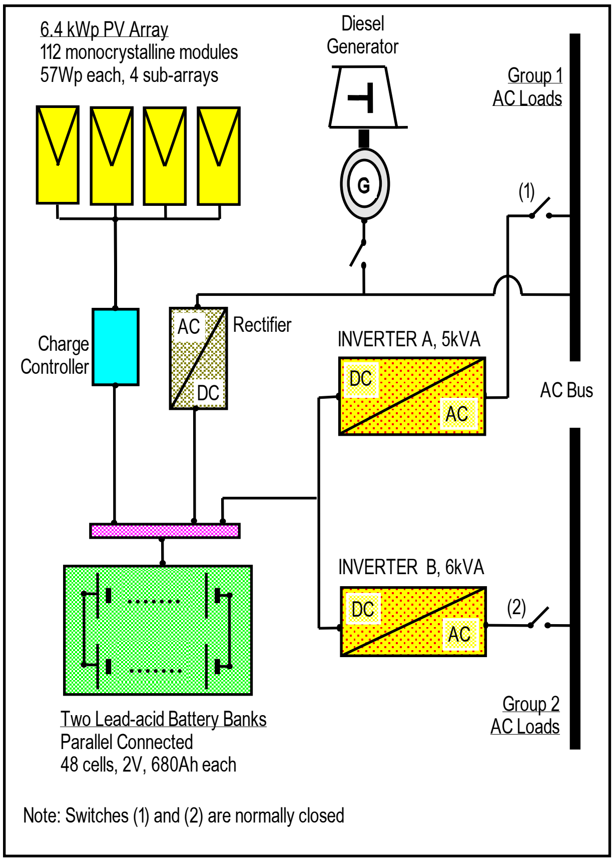

Figure 2. Schematic diagram of the Elounda PV plant

The photovoltaic station consists of 112 monocrystalline panels rated 57Wp each, giving 6.4kW total nominal power. The system was designed for an extended summer operation and the PV modules are inclined to 30^0 angle.

The DC bus of the system is 48V and the 220V AC side is divided in two parts, each supported by a single-phase inverter. The inverters are rated 5kVA and 6kVA and they were manufactured in Greece. Two inverters were installed in order to share the high start-up inductive loads and to increase system reliability. Additionally, in the case of malfunction of one inverter, the second can support all the electrical loads of the tourist facility.

Two battery banks are connected in parallel. The 2V battery cells are lead-acid, vented, tubular type and have 680Ah nominal capacity. The total storage capacity is 65.3kWh. Maintenance of the battery cells is limited to only periodical electrolyte density measurement and water level check.

2.3 Electrical Demand and PV Yield

The electrical loads include indoor and outdoor lighting, eleven small refrigerators (one for each bungalow), three professional middle size refrigerators, one professional freezer, one water pressure pump, one microwave oven, one waste water treatment unit, indoor and outdoor insect repellent devices and other ordinary household electrical appliances, e.g. TV sets, hair dryers etc.

The daily electrical demand in a typical summer day of each device is shown in Table 1.

Table 1. Typical daily demand at the Elounda bungalows in August

Electrical Device	Nom. Wattage	No of Units	Daily Op., [h]	Demand [Wh]
Indoor Lighting	30	110	1	3300
Outdoor Light.	25	30	6	4500
Bung. Refriger.	100	11	6	6600
Prof. Refriger.	400	3	11	13200
Prof. Freezer	300	1	11	3300
MW Oven	1200	1	1	1200
Pressure Pump	750	1	2	1500
Waste Treatm.	400	1	2	800
Insect Devices	20	15	5	1500
Other Electrical Appliances	200 (aver.)	22	1 (aver.)	4400 (aver.)
Total Daily Electrical Load				**40300**

The maximum daily energy requirement in July and August is around 40kWh, averaging at 35kWh over the extended summer tourist period. The summer daily load could be lessened by more than 10%, i.e. ≅4kWh if the existing incandescent indoor and outdoor lamps would be replaced by fluorescent energy saving lamps.

In Table 1, it is also noticeable the little daily operation of the bungalow low power refrigerators, i.e. 6h. This was achieved by placing the small refrigerators in the coolest area of the kitchen, taking advantage of the bioclimatic design of the buildings.

On the year round basis, the calculated monthly daily energy PV yield and the electrical demand is shown in Figure 3.

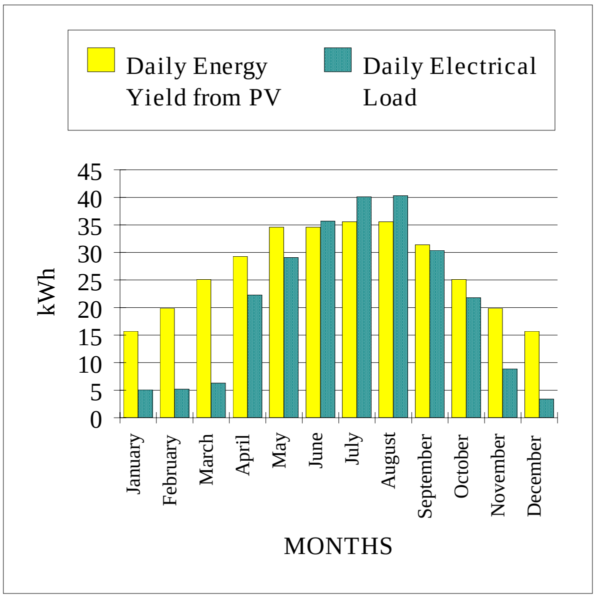

Figure 3. Calculated PV yield vs electrical load at the Elounda tourist resort

In long overcast winter periods or extreme load consumption e.g. July and August, one of the old diesel generators is used for battery charging and grid support.

2.4 PV System Costs

Although first class components have been used, the cost of this stand-alone PV application was kept at the lowest possible level. The overall cost was 67.2kECU, i.e. 10.5ECU/Wp installed, VAT 18% included. The cost breakdown is shown in Table 2.

Table 2. Component costs of the Elounda PV system

Component	Cost, [kECU]	% Total
PV Array	40.2	59.8
Support Structure	0.8	1.2
Lead-acid Batteries	9.0	13.4
Two Inverters	6.0	8.9
Charge Controller	2.5	3.7
Rectifier	1.7	2.5
Miscellaneous Equip.	2.5	3.7
Design, Engineering & Installation	3.4	5.1
Transportation	0.6	0.9
Commissioning	0.5	0.8
Total	67.2	100.0

The Greek government approved 30% funding for the PV stand-alone system at Elounda, under Law 1892/90 which supports incentives for the realisation of productive investments. The rest 70% was provided by the bungalow owner.

2.5 Experiences Encountered

The ecological character of the tourist facility at Elounda is obvious as all electrical loads and the hot water demand are satisfied by solar energy. In practice, the daily electrical load is covered by the energy delivered from the PV array and, only occasionally, diesel operation is needed, e.g. July and August. Last year, the fuel used was not more than 1tn instead of 18tn of previous years. Apart from petrol independence, the PV system owner has realised that solar electrification is a reliable power supply source. The investment is already paying back faster that expected due to the preference that environmentally conscious tourists show in solar electrified establishments.

The last summer’s experience has also shown that living conditions using solar energy supply systems implies no compromise for the tourists in terms of comfort, reliability in operation and facilities compared to conventional lodging. On the other hand, tourists themselves and other visitors have expressed interest in understanding the basic system operation parameters, e.g. solar irradiance daily availability, rational use of appliances etc. Tourists, along with their vacations, have the chance, at no additional cost, to get accustomed with the photovoltaic technology, the every day practice, the applications in remote and urban areas, the need for energy saving in a modern world etc. In this way, the short-term users of solar energy become energy conscious and have the chance to realise that renewable systems are mature technologies and provide alternative solutions to the increasing global energy problem.

3. IMPLEMENTATION OF PV SYSTEMS IN THE AEGEAN SEA AND ECOLOGICAL TOURISM

3.1 General

Promoting the idea of ecological tourism, stand-alone and small grid-connected PV systems, in the range 1kWp to 100kWp, are ideal for a wide range of applications in small and medium size islands. A capital cost of 9ECU/Wp is feasible and the PV modules could be integrated on south facing roofs of hotel buildings and bungalows, providing aesthetical adaptation.

Recent official figures, [2], indicate that the electrical energy demand increases every year in a way that local weak utility grids cannot further support, especially in the Aegean Sea islands. Measures are certainly taken by PPC to meet the increased demand of the tourist period although the energy cost is very high. However, electricity supply shortages in coastal zones occur on a daily basis, and malfunction or damage of delicate electrical appliances (e.g. air conditioners), have been reported. The unexpected repair works increase the operational cost and also affect the cost of living and the quality of life of the tourists.

Another aspect to be considered is the expansion of the tourist period. Specialists assume that due to the implied ecological character of solar electrification in a tourist resort, additional operation of one month prior and one month after the official opening and close respectively of the tourist period is expected.

3.2 Diesel Fuel Emissions

The environmental dimension is taken into account by calculating the pollution caused by diesel fuel burn. The emissions of two types of fuel used by PPC in the Greek islands are presented in Table 3, source [3].

Table 3. Pollutants from diesel fuel burn

	Emissions in gr per GJ of diesel fuel	
	Light Diesel, LD (10250 kcal/kg)	Heavy Diesel, HD (9600 kcal/kg)
CO_2	74000	78000
SO_2	209	1300
CO	20	20
NOx	1200	1200
CH_4	7	5
Particles	134	95
TOTAL	75570	80620

3.3 Power Generation and Implementation of PVs in the Aegean Sea Islands

A survey in 36 islands in the Aegean Sea concerned with the diesel installed capacity and operational experiences was carried out. Source of information was [4] and the data refer to 1994 operation. The islands presently connected to the mainland power generation system as well as, Crete and Rhodes were excluded from the calculations.

In order to assess the solar photovoltaic implementation, a 20% PV penetration on the minimum monthly load for each island was assumed.

Considering that the average annual solar radiation in the Aegean Sea is more than 1800kWh/m^2, the annual PV specific energy yield is calculated 1500kWh/kWp on average.

The environmental pollution was calculated by the LD and HD fuel consumption of the existing diesel engines. The fuel savings and emissions avoided due to PV implementation was calculated assuming an average diesel engine to electrical production efficiency 35%.

The results of the present operational conditions and the projected energy savings and environmental benefits due to PV implementation in 36 islands are presented in Table 4.

Table 4. Annual electricity production and potential for PV implementation in the islands of the Aegean Sea

DIESEL PRODUCTION		
Installed Diesel Engines Capacity	280	MW
Energy Production from Diesel	844262	MWh
Annual Cost of Petroleum	44370	kECU
Annual Cost for Electr. Production	83810	kECU
Annual Petroleum Consumption:		
Light Diesel, LD (10250kcal/kg)	51940	tn
Heavy Diesel, HD (9800kcal/kg)	150500	tn
Total Annual Fuel Consumption	202440	tn
Average Electricity Cost (diesel)	0.1	ECU/kWh
Electrical Energy Cost Variation	0.06-3.03	ECU/kWh
FUEL EMISSIONS		
Calculated Annual Emissions, [tn]	LD	HD
CO_2	164932	481730
SO_2	466	8029
CO	45	124
NOx	2675	7411
CH_4	16	31
Particles	296	587
Subtotal	168430	497912
Total	666342	
EXISTING RES		
Total Installed Wind Capacity	15.0	MWp
Total Installed PV Capacity	0.4	MW
Total Installed RES Capacity	15.4	MW
Total Energy Production from RES	34300	MWh
IMPLEMENTATION OF GRID-CONNECTED PVs		
Total Min. Potential PV Capacity	8.7	MWp
Estimated Annual PV Production	13050	MWh
Heavy Diesel Fuel Savings	3340	tn
Typical PV Energy Cost (lifetime)	0.34	ECU/kWh
Estim. Annual Emissions Avoided	Heavy Diesel	
CO_2	10471.2	tn
SO_2	174.6	tn
CO	2.7	tn
NOx	161.1	tn
CH_4	0.7	tn
Particles	12.7	tn
Total	10823	tn
STAND-ALONE PVs		
Potential Capacity	evaluation under way, [5]	

As is seen in Table 4, by considering a moderate 20% penetration on the lowest monthly annual electric load, the minimum capacity of grid-connected PV systems in the Aegean Sea islands is 8.7MWp. Apart from the expected expansion of the tourist period and the obvious economical benefits, there will be approximately 3300tn less diesel fuel usage and the environment will be saved from more than 11500tn pollutants annually. The data also show that the total emissions per electrical kWh produced is 0.82kg and 0.78kg for heavy diesel and light diesel fuel respectively. A market assessment for the potential of stand-alone PV systems including the Aegean Sea is currently under way.

In Table 4, the 0.1ECU/kWh electricity generation cost refers to only diesel fuel, O&M and transportation costs;

the capital investment for the purchase of diesel engines, installation, commissioning etc. has not been taken into account. Therefore, this value is not directly comparable to the 0.34ECU/kWh cost of the PVs which refers to current prices for photovoltaics and a system lifetime of 20 years. It is also important to mention that, in distant small islands, the kWh cost can reach 3ECU, showing that electricity production is extremely unprofitable.

From Table 4 is also calculated the capacity factor for diesel generation in the Aegean Sea islands, which, in 1994, was 34.4%. The existing RES (mainly wind), reached a capacity factor of 25.4% in the same year.

In concluding, photovoltaic energy is a useful aid in preventing further installation of diesel engines to cover the peak demand in the Aegean Sea islands.

4. OTHER PHOTOVOLTAIC APPLICATIONS IN TOURIST RESORTS IN GREECE

In the past, PPC has installed several small and medium size stand-alone PV stations in islands of the Aegean Sea. The intention was to demonstrate the PV technology in local communities by covering basic electrification needs, contributing in this way to the quality of life of the residents. The most important of these demonstration PV projects are in the islands of Kythnos (100kWp), Arki (27kWp), Antikythira (27kWp), Gavdos (21kWp), and more than 80 PV systems in small islands rated 0.7kWp each. Other private small-scale PV systems have been also installed in islands with tourist activities.

The application of PV technology in remote small inhabited islands has proven to be the means for tourist development. In the island of Arki for example, the number of tourists visited the place has increased by more than 150% in the last 3 years. The residents invest in developing the existing tourist infrastructure, e.g. building new apartments, offering better catering, improving the harbour facilities and the telecommunications etc. In this way, perspectives for the habitants to be involved in new activities are created and, most importantly, the local community resides in the island on a permanent basis, instead of considering to move in urban areas for a better future. Soon, the PV station at Arki will expand by another 10kWp array in order to cover the increased electrical loads and minimise the diesel use.

Under the 1996 THERMIE programme of DGXVII of the EC, [6], PPC in collaboration with CRES and other project partners undertook the design and installation of a 60kWp grid-connected PV station at the Sifnos island. The project commenced in December 1996 and the installation is anticipated to start in September 1997. The photovoltaic plant will be divided into 60 PV independent sub-arrays of 1kWp each. The annual yield of this PV plant is estimated in the order of 100MWh. The total project cost was predicted 811kECU, the monitoring phase excluded.

5. FINANCIAL POSSIBILITIES FOR PVs AND OTHER RES IN GREECE

Under the 1st phase of the 1996/97 Operational Energy Programme for productive investments in the sectors of Energy Saving and RES, 8 proposals for PV systems were submitted in March 1997 to the Ministry of Development by private enterprises. The total budget for these proposals was 33MECU. The OEP provides 55% subsidy to PV system installations. There were finally accepted three of these proposals for funding of 15MECU total budget and 8.25MECU subsidy.

The impressions of the 1st phase of the OEP refer to the good correspondence from the private sector for PV applications. This shows that the photovoltaic market in Greece is blooming and private enterprises are willing to invest in solar electrification. A drawback, however, of the 1st phase of OEP was the minimum 65kECU total budget required for a PV application. Also, photovoltaic electrification in households and small communities was not eligible for funding under the 1st phase of the OEP. It is, therefore, considered that in the forthcoming 2nd phase of the OEP, an opportunity for subsidising small PV systems will be given in order to provide opportunities for regional development.

Additionally, Law 1892 of 1990 refers to incentives for the realisation of productive investments in all sectors and includes renewable energies. Under this law, funding depends on the geographical position of the installation, promoting applications in rural areas.

It should be also mentioned that Law 2364/95, provides further incentives for the use of natural gas and renewable systems. According to article 7, the 75% of the expenditure for the purchase and installation of RES is eligible for deduction from the annual taxable income of the investor.

6. CONCLUSIONS

The design and operational experiences of an innovative photovoltaic system at the tourist bungalow complex at Elounda was presented in this paper. This stand-alone system has been appropriately designed for summer maximum electrical demand and operates successfully since June 1996. Apart from minimising the consumption of diesel fuel, the implied ecological character of the tourist facility has already expanded the tourist period due to the preference that environmentally conscious visitors show, with obvious economical benefits for the enterprise.

A preliminary scenario for the implementation of photovoltaics in the small and medium size islands of the Aegean Sea was also presented. The existing energy supply condition was examined and the environmental charge due to diesel fuel burn was calculated on an annual basis. The results showed that the minimum feasible PV capacity is 8.7MWp, contributing more than 13GWh electricity into the local grids and saving approximately 3300tn diesel fuel.

Governmental subsidiary actions for RES, e.g. through the Operational Energy Programme, could urge investors in the tourist sector to exploit the energy dimension of ecological tourism in existing facilities. Photovoltaic systems in tourist establishments would contribute to the electrical energy needs providing clean energy production. The ecological profile of a tourist facility would also improve and the tourist period is expected to expand with economical profits for the enterprise.

Tourist development in distant areas of tourist interest is now feasible as the dependence on fuel availability and transportation and O&M costs for the diesel engines can be avoided by implementing photovoltaics. Stand-alone PV systems are reliable and economically competitive to diesel power generation. The performance of photovoltaic systems is less site dependent compared to other RES, require little maintenance and can be integrated relatively easy on facades or south-facing roofs of buildings.

In Greece, the combination of high insolation levels and sunshine duration, the existing tourist infrastructure and the energy serious problems in the islands, create favourable conditions for the exploitation of PV technology. New perspectives and policy approaches towards the implementation of RES for electrification in rural areas could be created. In this way, the energy dimension in ecological tourism is introduced and a new market for photovoltaics could be sustained.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr J Chadjivassiliadis for his useful comments concerned with the information presented in this paper.

REFERENCES

[1]. "Towards Sustainability - The Tourism Sector", An EC Programme of Policy and Action in relation to the Environment and Sustainable Development COM(92) 23 final, Vol. 2, pp. 38-39

[2]. "The Greek Electric Power System 1995", Public Power Corporation, Strategy and Planning Department, April 1996

[3]. "The Climatic Change - The Hellenic Programme" Ministry of Environment and NTUA Technical Report, Part 1, Tables 2d & 3b, NTUA, Athens, October 1994

[4]. "Programme of the Autonomous Power Generation Stations 1995", Public Power Corporation, Department of Islands, Production Division, April 1996, 1995 Annual Report

[5]. "PV Markets in the Mediterranean - Assessment of the Potential and Barriers, Action Plan for Development" EC DGXVII 1996 THERMIE Programme, Project No THERMIE B-STR-0938-96-HE

[6]. "Installation of a Total of 60kWp of New Type Modular Photovoltaic System in the Greek Island of Sifnos", EC DGXVII 1996 THERMIE Programme, Project No SE-0135-96/GR-I-D

NOMENCLATURE

CRES: Centre for Renewable Energy Sources, Pikermi, Greece
HD: Heavy Diesel
LD: Light Diesel
NTUA: National Technical University of Athens
OEP: Operational Energy Programme
PPC: Public Power Corporation (electrical utility in Greece)
RES: Renewable Energy Sources