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The Effect Of The Financial Crisis On Electricity Cost For Remote Consumers: Case Study Samothrace (Greece)

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Abstract-The primary objective of this study is to estimate how the new taxes on fossil fuels in Greece, as a result of financial and economic crisis, has affected the electricity cost for a remote consumer. Two different scenarios were simulated, comparing the possible hybrid system configurations. From HOMER software simulation, it has been demonstrated that, for a typical house in Samothrace, a small Greek island situated in the northern Aegean Sea, the hybrid Wind–PV–Battery system is the optimum solution. For a typical country house in Samothrace the use of a LPG generator has financial and environmental benefits compared to a Diesel generator. However the use of environment friendly renewable energy sources is becoming increasingly important.

Keywords-Hybrid systems; Renewable energy; Financial crisis; LPG; Samothrace.

1. Introduction

Energy is an essential ingredient in economic development and global electricity demand is steadily increasing as developed countries run on to expand and developing ones grow even faster. Nowadays, environmental concern in relation to the impact of fossil fuel based power generation, as well as financial and health subjects are increasing too. Moreover, the worldwide economic and political circumstances that tend to make countries more dependent on their own energy resources have caused increasing attention in the development and use of renewable energy [1-4].

Renewable energy sources, such as solar and wind energies, are inexhaustible, clean, environmentally friendly and more secure. Although, huge funds in research money and numerous hours of scientific effort have been spent, up to the present time no single technology has proven itself to be the panacea to the nation's energy problems. However, the individual fluctuation of the wind and solar resources can be overcome using hybrid renewable energy systems with battery backup. Applications of hybrid systems range from small power supplies, for remote home providing electrical energy, to village electrification for remote communities. Special effort has been given to the optimization of stand-alone hybrid systems in terms of both energy and economy [5-6].

The utilization of renewable energy is especially suitable for remote areas and islands. Commonly the isolated consumers have no direct access to reliable electrical networks and most of them are obliged to depend on the operation of small autonomous generators consuming considerable amounts mainly from oil and its related products. These generators has really low initial capital cost but very high operational cost requiring frequent maintenance and presenting a short period of service [7]. In Greece due to the country's unique geography exist several thousands of remote consumers [8-9], placed on the numerous mountains and small or medium sized islands. Tourism is one of the most important economic activities in the islands and there is a serious seasonal electricity consumption variation [10].

The objectives of this work are to evaluate how the financial and economic crisis in Greece has brought new data and if there are more viable solutions from the small diesel engines in order to produce electricity. For a small Greece Island namely Samothrace we consider two case studies: one with occupancy rate 100% and another where corresponding to a typical country house. HOMER (Hybrid Optimization Model for Electric Renewables) version 2.68 developed by National Renewable Energy Laboratory (NREL) was used as the simulation and optimisation tool [11]. The assessment criterion of the analysis is the net present cost (NPC) and the cost of energy (COE).

2. Case study

Samothrace (40°29′N, 25°31′E) is a relatively small Greek island situated in the northern Aegean Sea (Fig. 1) [12]. Samothrace has an area of 180.364 square km and a population of about 2723 (2001 census).The 80% of the island is mountainous and it is the second highest island in the Aegean; with Mt. Fengari rising to 1611 m. Samothrace has a Mediterranean climate with mild winters and fairly cool summers. The inhabitants live by fishing and tourism. Access to the island is by boat only.

The island's most famous site is the Sanctuary of the Great Gods, place of important Hellenic and pre-Hellenic religious ceremonies. The island presents big tourist development during the summer months (59360 visitors in 2001) [13] due to its appreciable natural resources (coasts, beaches, climbing, several waterfalls, entertainment). That has as a result the increase of electric power demand.

According to Giannoulis and Haralambopoulos [14] the electrical power demand in all Greek islands in the Aegean Sea during the last decade presents a significant annual increase exceeding the 5% in annual basis. Kaldelis et al. [9] note that electricity consumption during the summer, due to the visiting tourists, is more than twice the corresponding spring besides, on an hourly basis; there is significant fluctuation on the load requirement throughout the day. Unfortunately measured load information over the year in Samothrace was not available. In order to synthesize the load profile data, different previous works are combined. Prodromidis and Coutelieris [15] divided a year into three periods and for every simulated period the days also divided into two categories: weekend and weekday. A previous work done from Kaldelis et al. [16] has been a great help in determining the hourly load variation for Samothrace. However the size and shape of load profile fluctuate from hour to hour and from day to day. With the purpose to randomize the load profile and make it more realistic a 10% noise level has been added on a daily and hourly basis. The expected load consumption profiles of the area for a typical house and for a typical country house are shown in Fig. 2 and 3 respectively

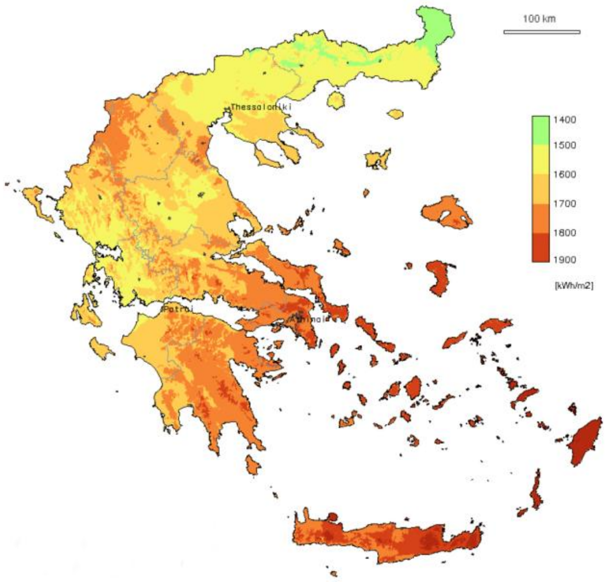


Fig.1. Location of the Samothrace Island

The performance from a hybrid system is strongly dependent on the climatic conditions and accurate meteorological data in a target location is essential. In this job the long term meteorological parameters are obtained from the HNMS (Hellenic National Meteorological Service) [17]. Among the other Greek Islands the Samothrace has the second minimum solar irradiation (see Fig. 1).The monthly average daily global solar radiation and the monthly average daily clearness index in Samothrace are given in Fig. 4.According to Fig. 4 the highest values of solar radiation are observed during the summer months when the load requirements are higher.

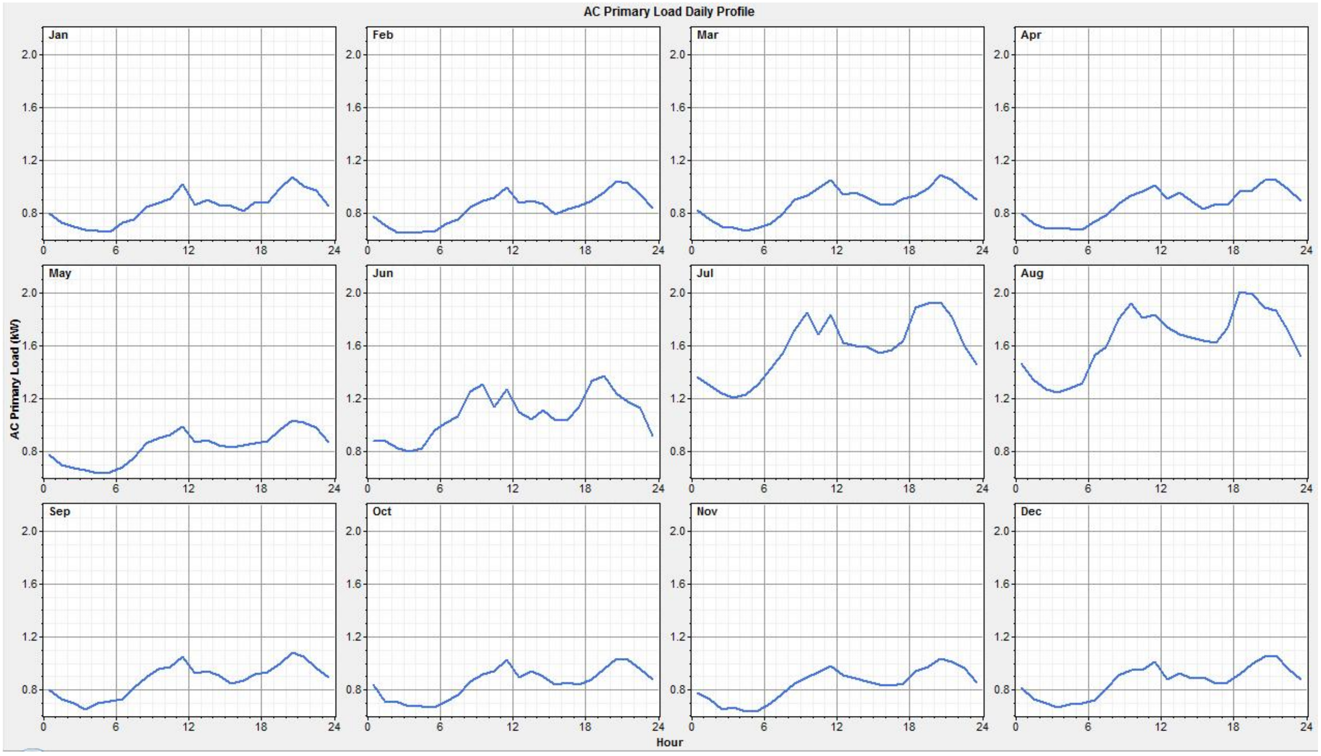


Fig.2. Expected yearly load consumption profile for a typical house in Samothrace

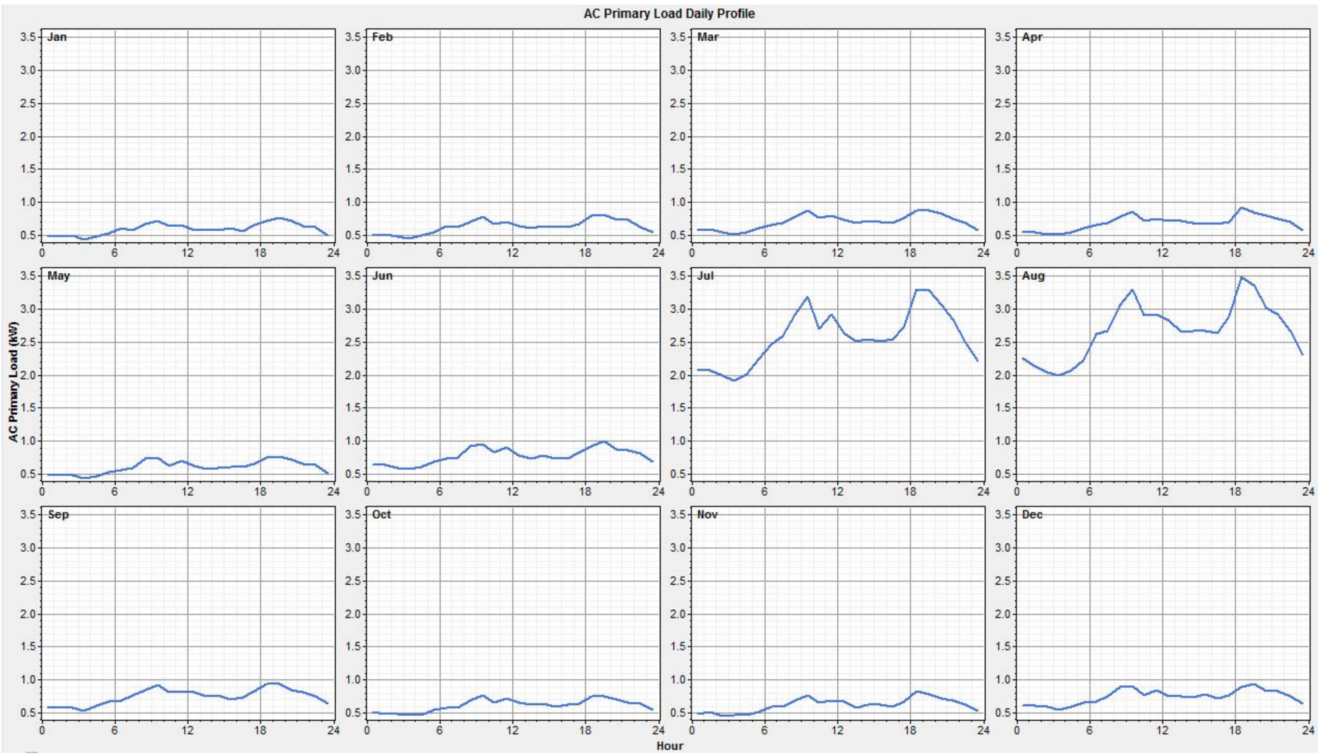


Fig.3. Expected yearly load consumption profile for a typical country house in Samothrace

The hourly average wind speeds are presented in Fig. 5. As it can be seen, there is a considerable variation of the monthly average wind speed. Wind speeds are generally higher during the months January to March as compared to other months however the second highest wind energy densities in Samothrace were observed during July. In the present study, wind turbine of 2.5 kW from Wind Energy Solution is used. The wind power curve of the WES 5 Tulipo wind machine is shown in Fig.

6. WES 5 Tulipo, has 5 m rotor diameter and 6.25 m of tower [18].

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.401	1.641
February	0.440	2.422
March	0.461	3.460
April	0.492	4.698
May	0.541	5.950
June	0.591	6.856
July	0.600	6.771
August	0.611	6.154
September	0.581	4.761
October	0.531	3.233
November	0.442	1.947
December	0.396	1.452
Average:	0.531	4.121

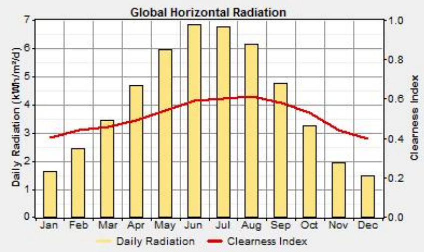


Fig.4. Average daily radiation

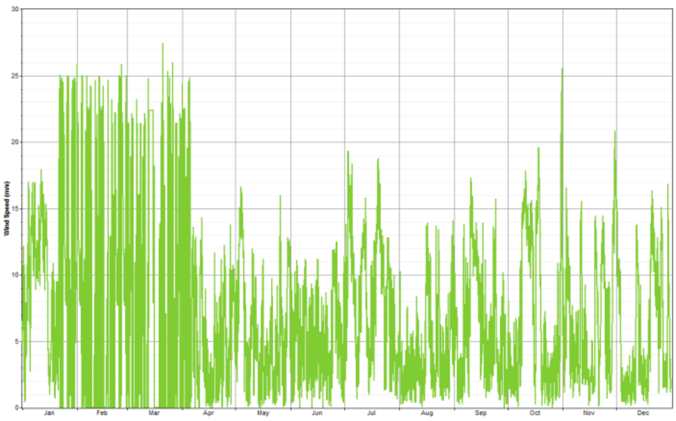


Fig.5. Average hourly wind speed for 3 years

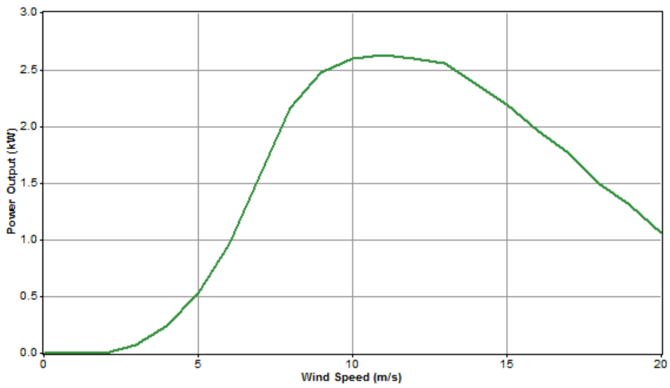


Fig.6. WES 5 Tulipo wind turbine power curve

The financial and economic crisis in Greece has brought new taxes in the Greek citizens and in the fossil heating fuels. According to the data from the Hellenic Minister of development [19], duringthe depression (October 2009 – May 2011) the diesel-oil and the benzene price were rising more than 55%. In the same period the LPG was rising about of 23%. The dramatically increased prices for diesel and unleaded encourage many car owners to modify theirs cars in order to consume LPG. Today, in Samothrace 1 L diesel costs more than 1.4 € while the LPG price is approximately 0.8 €/L.

3. Economic analysis of hybrid energy systems with HOMER Software

HOMER is a modelling tool that facilitates design of standalone electric power systems [11]. HOMER describes the levelized COE as the average cost/kWh of useful electrical energy produced by the system. To estimate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production. The equation for the COE defined as:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}} \qquad (1)$$

where$C_{ann,tot}$ is the total annualized cost (€/yr), $E_{prim,AC}$ is AC primary load served (kWh/year), $E_{prim,DC}$ is DC primary load served (kWh/year), $E_{grid,sales}$ is total grid sales (kWh/year). The total net present cost is HOMER's main economicoutput. All systems are ranked corresponding to the net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost. HOMER computes the total NPC using the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \qquad (2)$$

where CRF is the capital recovery factor, i is the interest rate (%) and R_{proj} is the project lifetime(yr).The CRF expressed by equation:

$$CRF = \frac{i(i+1)^{R_{proj}}}{(i+1)^{R_{proj}} - 1} \qquad (3)$$

In this work different hybrid options were analyzed to get an optimized hybrid system sizing. The initial capital cost, replacement cost, maintenance cost and lifetime of each component are shown in Table 1. Costs and equipment performances data have been assumed by market surveys and by literature [20-22]. The project life time has been considered to be 25 yr and the annual real interest rate has been taken as 6%.

Table 1. Components of the hybrid system analysis.

Characteristics	Diesel generator	LPG generator	PV module	Wind turbine	Battery	Converter
Model	Typical	Typical	Typical	WES 5 Tulipo	Trojan T-105	Typical
Power	1 kW	1 kW	1 kW	2.5 kW	Nominal voltage 6V nominal capacity 225Ah (1.35kWh)	1 kW
Life time	30000 h	8000 h	25 year	15 year	Lifetime throughput 845kWh	15 year
Price	250€	320 €	4000€/kWp	5000€/turbine	121€/battery	1000€/kW
Replacement	250€	320 €	4000€/kWp	4000€/turbine	108€/battery	1000€/kW
Maintenance	0.15€/h	0.2 €/h	3€/kW	50€/turbine	1€/battery	null

4. Results and discussion

4.1. Typical house

Many simulations for a range of scenarios have been made by considering different combinations of wind generators, PV panels, diesel and LPG generators. Based on the HOMER modelling, the optimum system for a typical household in Samothrace is a hybrid Wind–PV–Battery system, with 1 WES 5 Tulipo wind generator, 3 kW solar panels, 41.85 kWh of batteries and 2 kW of power converter (Fig. 7). This "optimum" system uses 100% renewable energy in which 65% electricity comes from wind source (8463 kWh/yr) and 35% electricity comes from solar radiation (4548 kWh/yr) with an annual capacity of shortage 10%. The COE for the Wind–PV–Battery system is estimated at around 0.312 €/kWh with NPC 28462 €. The monthly average electric production is shown in Fig. 8. There are no CO_2 and SO_2 emissions as there is no fossil fuels generator.

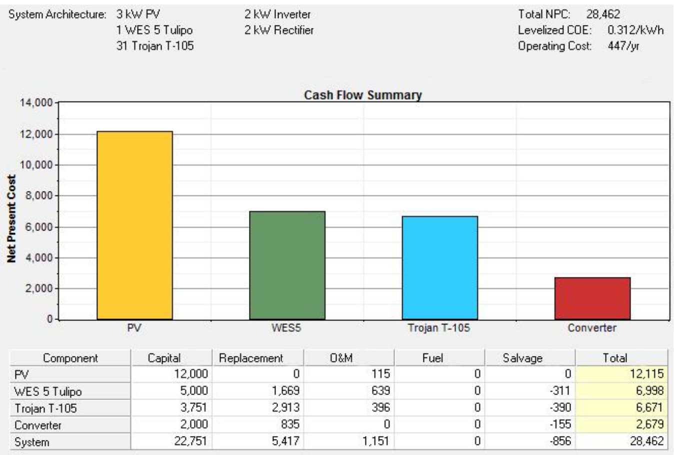


Fig 7. The cash flow summary for the optimum system (typical house).

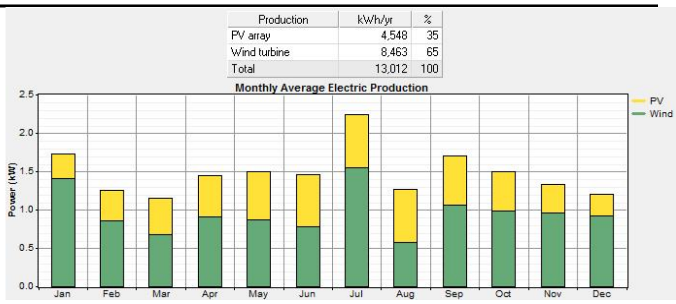


Fig.8. Monthly mean power contribution for the optimum system (typical house)

With the intention to give a general overview of the situation, sensitivity analysis is also realized. Wind speed with six discrete values (5, 5.5, 6, 6.65, 7, and 7.5 m/s), solar radiation with five discrete values (3.75, 4, 4.12, 4.25, and 4.5 kWh/m2 per day) diesel price with 11 discrete values (0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, and 1.9 €/L), and LPG price with 11 discrete values (0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1, 1.05 €/L) were used as sensitivity variables. The results, which obtained from the sensitivity analysis in the form of a sensitivity graph is also exhibited in Fig. 9. In any case the choice of the hybrid Wind–PV–Battery system is the only feasible solution because both diesel and LPG generators has high operating cost.

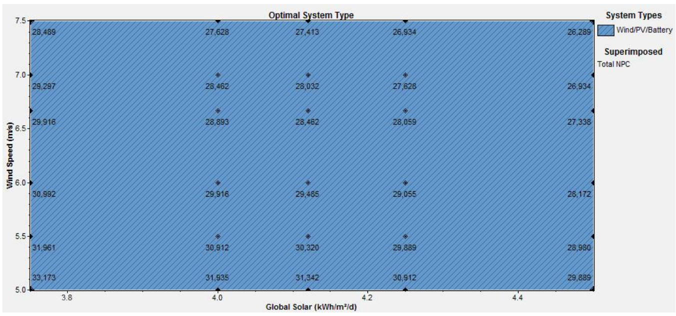
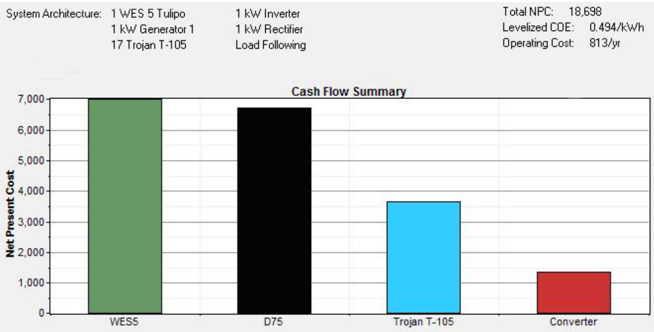


Fig.9. Sensitivity analysis of wind speed to solar radiation for Samothrace (typical house)

4.2. Typical country house

In this scenario the electricity load is considerable lower during the year with exception the period of summer (Fig. 3). These load requirements are more suitable for diesel or LPG generators because the hours of operation are limited. The greatest advantage of diesel generator in connection with LPG generators is the actual fact that the diesel generators are more durable (30000 hours before replacement – compared to 8000 hours with a LPG). If we consider that someone use a diesel generator energy yield–from different components of the most feasible hybrid Wind–Diesel generator–Battery system (comprised of WES 5 Tulipo wind generator, Diesel generator with a rated power of 1 kW and 22.95 kWh storage batteries in addition to 1 kW converter) with 93% wind penetration—is exhibited in Fig. 10. The wind generator produces 8463 kWh/yr (93% of the total energy served), while Diesel generator produces 7% of the energy i.e. 639 kWh/yr. According to the HOMER calculations in this case the diesel generator operates 1163 hr/yr. NPC of the system is found as 18698 € and 0.494 €/kWh is the cost of energy (Fig. 11).



Component	Capital	Replacement	O&M	Fuel	Salvage	Total
WES 5 Tulipo	5,000	1,669	639	0	-311	6,998
Generator 1	250	71	2,230	4,200	-49	6,702
Trojan T-105	2,057	1,598	217	0	-214	3,658
Converter	1,000	417	0	0	-78	1,340
System	8,307	3,755	3,087	4,200	-651	18,698

Fig.10. The cash flow summary for the hybrid Wind–Diesel generator–Battery system (country house)

Simulation of all feasible hybrid Wind–(PV)–Diesel generator–Battery systems, which can meet the required load in their respective search space for each of the sensitivity values was performed. Wind speeds of (5, 5.5, 6, 6.65, 7, and 7.5 m/s), solar radiation of (3.75, 4, 4.12, 4.25, and 4.5 kWh/m2 per day) and diesel prices of (0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, and 1.9 €/L), were used as sensitivity variables. Fig. 12 shows the result of the sensitivity analysis over a wide range of wind speed and solar radiation. For wind speedlower than 6 m/s the penetrations of PV panels are financial viable and the Wind–PV–Diesel generator–Battery systems are optimal. Fig. 13 displays the appropriate implementation of hybrid systems under different wind speed and diesel price. From Fig. 13 is obvious that as the diesel price increases the penetration of PV increases also. This happen because the operation cost of diesel generators increases and make the PV generators more financial viable than diesel generators.

Production	kWh/yr	%
Wind turbine	8,463	93
Generator 1	639	7
Total	9,102	100

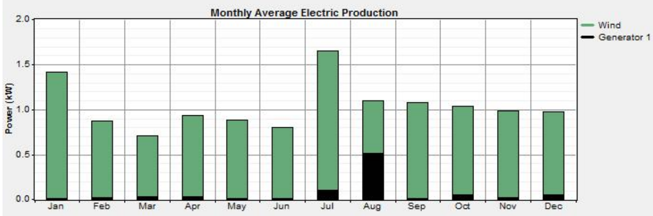


Fig.11. Annual energy production from the hybrid Wind–Diesel generator–Battery system (country house)

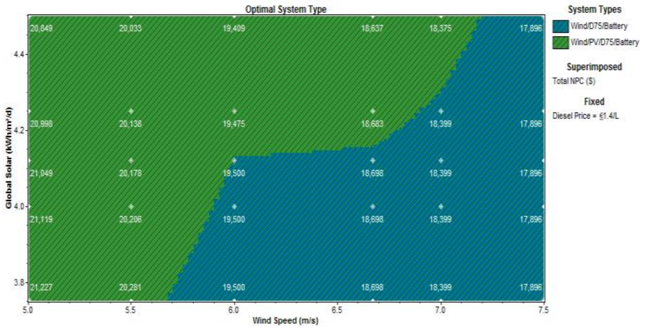


Fig.12. Sensitivity of wind speed to solar radiation for the hybrid Wind–Diesel generator–Battery system (country house).

In case with a LPG generator replaces the diesel generator, the "optimum" system has the similar components and performance but lower NPC and COE. Namely the NPC is the 18294 € and COE is 0.484 €/kWh (Fig. 14). Three sensitivity variables (wind speed, solar irradiation and LPG price) are considered in this analysis. Fig. 15 exhibits the sensitivity analysis in term of wind speed (5, 5.5, 6, 6.65, 7, and 7.5 m/s) and solar irradiation (3.75, 4, 4.12, 4.25, and 4.5 kWh/m^2 per day). One significant observation is that, due to the lower operating costs (776 €/yr versus 813 €/yr), the PV panels come into the picture in less occasions in comparison with the Wind–PV–Diesel generator–Battery systems (see Fig. 12). Generally the wind speed and the fuel cost are usually site–dependent, so if we consider these parameters as sensitivities variables with values 5.5, 6, 6.48, 7 and 7.5 m/s for the wind speed and 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1 and 1.05 €/L for the LPG price, the results are shown in Fig. 16. Fig. 16 has the same trend with Fig. 13. Clearly as the LPG price raises the hybrid system with Wind–PV–LPG generator–Battery is the optimal system with the increase in the PV penetration.

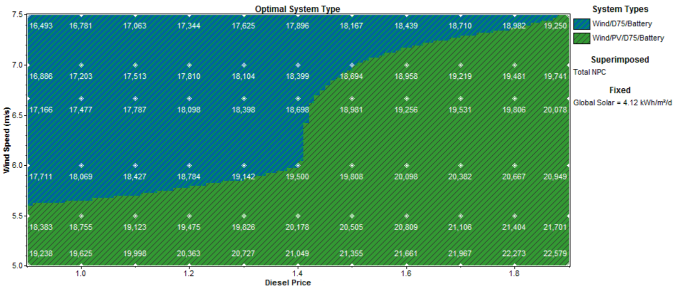
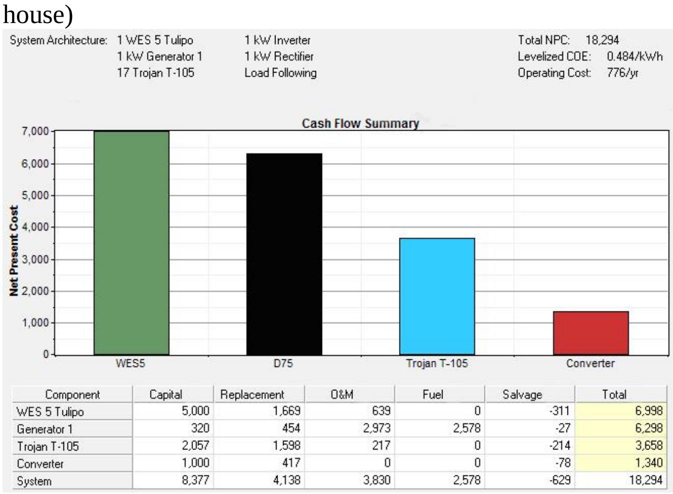


Fig.13. Sensitivity of wind speed to diesel price for the hybrid Wind–Diesel generator–Battery system (country house)



Component	Capital	Replacement	O&M	Fuel	Salvage	Total
WES 5 Tulipo	5,000	1,669	639	0	-311	6,998
Generator 1	320	454	2,973	2,578	-27	6,298
Trojan T-105	2,057	1,598	217	0	-214	3,658
Converter	1,000	417	0	0	-78	1,340
System	8,377	4,138	3,830	2,578	-629	18,294

Fig.14. Economic and performance parameters for the hybrid Wind–LPG generator–Battery system (country house).

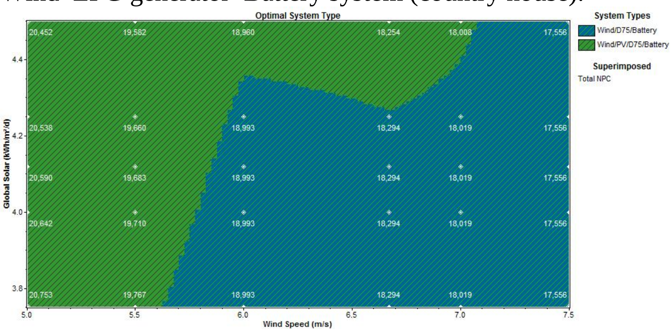


Fig.15. Sensitivity of wind speed to solar radiation for the hybrid Wind–LPG generator–Battery system (country house)

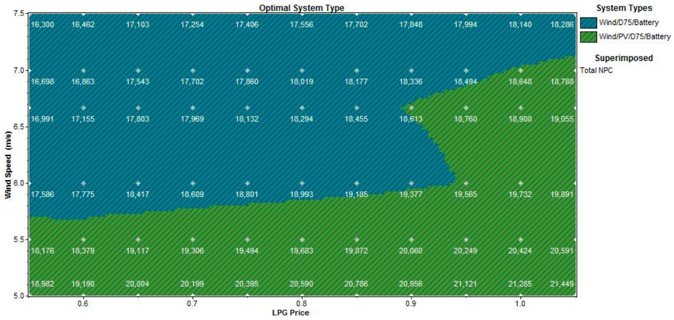


Fig.16. Sensitivity of wind speed to diesel price for the hybrid Wind–LPG generator–Battery system (country house).

Before the financial crisis the optimum hybrid system (Wind–Diesel generator–Battery system) for a typical country house in Samothrace had NPC equal to 17166 €. With new economic data the NPC of the system is found as 18698 €. The corresponding values for the Wind–LPG generator–Battery system are 17803 € and 18294 € respectively. The iniquitous price of diesel changed the balance and LPG seems as better solution. However considering that fossil fuel prices are continuously increasing, a future raise in the price diesel or LPG is the most probable scenario, which will encourage inhabitants to invest in renewable sources such as the wind generators or the PV panels.

Unfortunately both diesel and LPG causes air pollution. In terms of harmful gas emissions a comparison between the two systems is done. It should be noted that the analysis assumed no penalty cost to be imposed for the pollutant. Homer calculates six pollutants as simulation outputs: carbon dioxide (CO2), carbon monoxide (CO), unburned hydrocarbons (UHC), particulate matter (PM), sulfur dioxide (SO2) and nitrogen oxides (NOx). Total emissions due to operation of the systems are listed on Table 2. As shown in Table 2, for hybrid Wind–Diesel generator–Battery system, the total emissions of pollutants were 634.654 kg/year. For the hybrid Wind–LPG generator–Battery system, the total emissions were 400.375 kg/year. According to the results LPG generators except from financial benefits offer cleaner–burning fuel than a standard diesel generators.

Table 2. Pollutants emitted from the power systems

	Emissions (kg/year)	
Pollutant	Wind–Diesel generator–Battery system	Wind–LPG generator–Battery system
CO_2	618	383
CO	1.53	1.64
UHC	0.169	0.182
PM	0.115	0.124
SO_2	1.24	0.829
NO_x	13.6	14.6

5. Conclusions

Samothrace the Greek Islands with the second minimum solar radiation was chosen in order to evaluate how the financial and economic crisis in Greece has affected the cost of electricity both for a typical of grid house and for a typical of grid country house. HOMER software was used in order to perform all quantifications. In the first scenario of this study (a typical house) at present diesel and LPG cost the results demonstrate that the hybrid Wind–PV–Battery system is the optimum solution. It is also clear that the maximum electricity comes from wind which predicts that wind is more feasible than the solar in Samothrace.

In the second scenario (typical country house) the simulations indicate that with new prices, owing to the additional taxes in the fossil fuels, the Wind–LPG generator–Battery system has lower NPC and COE compared to the Wind–Diesel generator–Battery system. From environmental point of view, it was found that LPG generators offer not only financial benefits but also cause considerable lower air pollution. The simulations indicate also that, due to the additional taxes in the fossil fuels, the PV generators become continuously more financial viable. However, considering that the financial crisis is a worldwide problem, which is more acute in some counties like Greece, and bearing in mind that the fossil fuel prices are continuously raising, while the PV and wind generator cost are constantly decreasing, the main deduction from this study has global interest. The use of environment friendly renewable energy sources is the only solution with future prospects and the financial crisis which heighten a price of the oil make the renewable energy sources a feasible solution.

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