Nikos Nikolopoulos - Dr. Mechanical Engineer NTUA,

Andreas Sfakianakis - Mechanical Engineer, MSc, Board member of Gnomagoras Nisyros Association

NISYROS AND RES APPLICATION SCENARIOS FOR ELECTRICITY PRODUCTION

In this article, technologies and measures are going to be presented, that could potentially be exploited to cover the electricity demands of the island of Nisyros, as they are currently formed without requiring additional interventions which would have questionable long-term effect on the quality of life of residents and on tourism in which the residents of Nisyros have significantly invested. The proposed application scenarios for Renewable Energy Sources (RES) will be investigated through the application of certified software regarding their sustainability both in the short- and in the long–term time scale. The solutions examined consist of options that do not involve the use of geothermal energy for electricity production (high enthalpy utilization facility). The alternative systems listed may have been implemented only on a pilot or small scale, but the production of electricity from geothermal energy in Greece is a solution that is characterized by high levels of uncertainty. A typical example is the island of Milos, where the application of geothermal energy by means of high enthalpy geothermal fluids proved to be at least uncertain or unsuccessful in recent years.

The scenarios which are explored as credible alternatives and are briefly presented in this article include:

- the installation of photovoltaic parks to generate electricity,
- the installation of wind parks in areas decentralized from the settlements of Nisyros (Mandraki, Pali, Nikia and Emporios)
- the possibility of installing even floating offshore wind parks
- the installation of decentralized CHP with Solid Oxide Fuel Cells (SOFC) and Internal Combustion Engines (ICE), and
- the mild exploitation of geothermal field of Nisyros.

The aim of this presentation is to investigate, at a level of strategy, the applicability of such technologies in Nisyros and the effects or risks that this application can potentially induce. Criteria for the application of these systems are the economic efficiency, realism and feasibility, social acceptance, environmental safety and energy efficiency.

Photovoltaic Systems

The photovoltaic effect was discovered in 1839 and was put into practice at the end of 1950 in satellite systems in space. Photovoltaic systems can convert solar energy into electricity. A typical PV system consists of PV modules (panels) and electronic systems which manage the power generated by the photovoltaic generators. In autonomous photovoltaic systems there is also an additional energy storage system that uses batteries.

A typical photovoltaic array consists of one or more photovoltaic panels that are connected together. When the solar panels are exposed to sunlight, they convert about 14% of the incoming solar energy into electricity - although many modern panels have reached efficiencies close to 20% or above. The conversion of solar energy into electricity is quiet, reliable and has no impact on the environment.

Categories of autonomous photovoltaic systems [1]

- Small photovoltaic systems

  The systems in this category are used to cover low energy intensive applications.

- Autonomous photovoltaic systems

  This category includes electricity generation systems for houses and small communities, as in the case of Nisyros. Additionally, they are used for:

- Power supply of monasteries.
- Water pumping.
- Exterior lighting of public spaces (streets, squares, airports, etc.)
- Telecommunication systems, telematic measurements and alarms.
- Agricultural tasks such as water pumping, aquaculture, cooling of agricultural products and medicines, etc.

  The third category is:

- Uninterruptible power supply systems - UPS, which are used to provide backup power.

The main advantages of PV systems consist of:

- zero pollution
- quiet operation
- reliability and long life (up to 30 years)
- independence from fuel supply to remote locations, like Nisyros
- extendable according to the needs
- minimal maintenance

The photovoltaic systems bring considerable benefits to the environment and society; including benefits for the consumers, energy market and sustainable and green development.

Solar energy is clean, inexhaustible, mild and truly renewable. The solar radiation is not controlled by anyone and it is an inexhaustible domestic energy resource, which provides independence, predictability and safety in energy supply.

The photovoltaic systems, which convert sunlight into electricity, are considered as ideal energy conversion systems, as they use the most available energy source, particularly in Greece (strategic advantage of our country in relation to the others) for electricity production. The environmental benefits of PV are undisputed. Every kWh generated by solar panels, rather than conventional fuels, prevents the release of approximately 1 kg of CO_2 in the atmosphere (based on the current energy mix in Greece and the average network losses). A typical 1 kW solar system prevents the release of 1.3 t of CO_2 per year, as much as two acres of forest trees would absorb. Furthermore, it results in less emission of other dangerous pollutants, such as particulate matter, nitrogen oxides, sulphur compounds, etc.

Conventional Wind Turbines

Among other types of Renewable Energy, particularly in Greece, wind energy using wind turbines is dominant. The main advantages of its implementation are the following [2]:

- Wind is an inexhaustible source of energy, which is not only provided free, but also abundantly in areas like the Greek islands.
- Wind power is a technically mature, economically competitive and environmentally friendly energy option.
- From the production of 1 kWh through wind turbines, the combustion of 0.2 litres of petroleum is avoided. The energy that feeds every year a 10 MW *Wind Park (W/P)*, is equivalent to an average of 9,000 tons of petroleum. Thus, Greece is released from oil imports, which are detrimental for national balance as it is getting constantly more expensive.
- Compared with conventional plants *(Oil stations, natural gas stations, lignite thermal power stations), they* occupy much less space. Additionally, the land of the wind farm can continue having its previous use before the wind farm i.e. cultivation and livestock.
- According to studies, one MW installation of wind turbines creates an average of 17.7 labour years, involving the design, construction, maintenance and supervision of the W/P (*wind park)*. In contrast, conventional el. energy production technologies (e.g. petroleum) account for only 8 labour years per MW. Investments in wind energy are a feasible and sustainable action for a SME business. They can stimulate local industry and the construction industry.
- The wind turbines are a dispersed energy source and can enhance the local electricity network. Specifically, siting of wind parks contributes in reduced transmission losses of el. energy, because energy will be produced near the place of consumption.
- It is not detrimental to the local environment with hazardous air pollutants, carbon monoxide, sulphur dioxide, carcinogenic micro- particles, etc., as occurs with conventional power plants.
- It enhances energy independence and safety, something very important for our country and Europe in general.
- It helps to decentralize the energy system, reducing transmission losses.

Despite its advantages, the main problem addressed in implementation is the reactions of local communities because of the noise induced by their operation. This is the only real problem, but easier now to control and prevent. Noise emitted from wind turbines can be classified into two categories, depending on their origin: namely mechanical and aerodynamic.

- The first comes from rotating mechanical parts (gearboxes, electric generator, bearings, etc.)
- The second derives from the rotation of the blades.

The noise from the operation of the wind turbine mechanical parts, in recent years is eliminated both by internal acoustic soundproofing of the shell of the structure and by soundproof panels and vibration mounting pads. Similarly, the aerodynamic noise (turning blades) is treated with careful design, understanding to a greater extent the basic principles of aerodynamics.

The level of perceived noise from a modern standards wind turbine at a distance of 200 meters is less than that corresponding to the ambient noise level of a small provincial town and certainly not a source of annoyance. Given the legislated requirement for the wind turbines to be installed at a minimum distance of 500 meters from settlements, the level is even lower and corresponds to that of a quiet living room. Furthermore, at the wind speed in which wind turbines operate, the natural noise (wind in trees and bushes) overlaps any noise coming from their own.

The aforementioned as disadvantages of the wind turbines are not really problems, only unsubstantiated arguments of those opposed to the clean energy policy for the sake of interest:

The noise. According to studies the sound pressure level of a modern wind turbine does not exceed 50-60 dB at 40 m, which is the level of normal speech. For a house 500 meters away from a wind turbine, when the wind blows from the wind turbine to the house, the sound pressure level is about 35 dB, as in a quiet home, which means it will practically not be heard at all. In addition, if you visit the Demonstration Wind Park of CRES at Lavrio, you would find that the sound of a wind turbine is like the rustling of a reed bed when the wind blows.

The aesthetic pollution. How the wind turbines form aesthetic pollution is purely a subjective matter. Why does the population of Attica basin tolerate the antennas on Mount Hymettus? It is the need of free radio and TV that makes them necessary, and so they are not a disturbance for anyone. Among others, the sight of the rotation of the propellers of the turbines is reminiscent of the old windmills that are considered a pleasant sight for many.

The sites which will be judged capable of hosting a wind farm in Nisyros will come up after a special study of wind potential in different places. From observation, the areas to the West and North-West of the island are the ones with the highest wind potential, since fairly strong winds blow there most of the year.

A good solution would be the exploitation of Gyali Island for the installation of wind parks. The eastern side of the island, behind the Perlite mine could possibly be a widely accepted solution, as it shows high potential, but is also far from settlements. This solution might also be cost-effective in terms of initial investment, as the expensive technologies for noise reduction would not be necessary to apply.

Offshore wind turbines

To completely eliminate the supposed problem of noise from the exploitation of wind energy from wind turbines to generate electricity, at least in the area of Nisyros, a solution is the construction of offshore wind turbines. The potential for electricity generation from offshore wind turbines is theoretically able to cover the needs of the whole Europe [3,4]. Greenpeace ([5]) estimates that in the case of Greece the electricity from offshore wind turbines can be up to 2.755 TWh per year in 2020 . This energy will be produced by offshore wind parks with a total installed capacity of 3.3GW. To understand the size class of this electric power production, it is said to correspond to 4.8% of the interconnected power system for the year 2008 ([6]).

Table 1. Potential of offshore wind turbines installation in Greece according to Greenpeace.

Period	Annual electricity (GWh)	Installed Capacity (GW)	Required surface (km^2)
2003 - 2010	1,141	0.92	115
2011 - 2015	412	0.66	82
2016 - 2020	1,203	1.73	216
2020 (total)	2,755	3.30	413

However, due to the fact that in Greece the sea depth increases much on the distance from the coast, this solution may not be realistic. This could be attributed primarily to the fact that in offshore wind parks, the sea depth as a function of distance from the coast is the main factor affecting the cost of investment ([7]). According to the work of Pantaleo et al. the basic physical restrictions relating to offshore wind turbines are mainly the depth and slope of the seabed, which must not exceed 35m and 5% respectively.

Therefore a suitable solution for these areas, which are characterized by a lack of shallow waters, could be floating offshore wind parks [3].

The wind turbines of floating wind parks, in contrast to those of conventional offshore wind parks are not supported or anchored to the ground, but float on water instead. Figure 1 presents various scenarios of floating wind turbine support (ECOR, 2008). Floating support systems have not yet reached a commercial level (ECOR, 2008), with the exception of the stabilization system with ballast (ballast stabilized) which has been used in Hywind_, the first large-scale 2.3MW floating wind turbine (Breton and Moe, [8]).

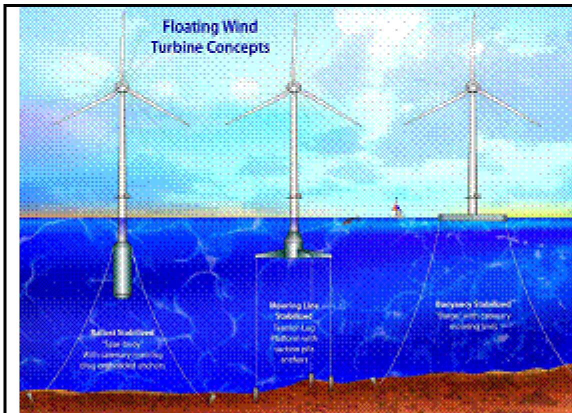	
Figure 1. Floating wind turbine support systems [6].	Figure 2. Visualization of a wind farm for a distance of 0.9 miles away from the coast. [6]

The advantages of floating wind turbines are numerous and can be summarized as follows:

- The wind speeds in areas away from the coast is much higher and sustained consistently with the consequence not only of the potential for electricity to be higher but of the corresponding capacity factors to be higher as well [6].
- Levels of turbulence in the wind are lower away from the coast. This fact results in smaller stresses and thus the construction can be lighter and cheaper. [6]
- The sound produced by floating wind parks does not necessarily have to be very low, and therefore it is not a restricting factor, as reported in conventional wind turbines [6].

This proposed technology can potentially be located in offshore areas in the North-West side of the island, where the wind potential is characterized quite high. This area also has the advantage of being away from all the settlements of the island, so there is no issue of visual impact, while it is also located outside navigation routes.

Combined Heat and Power - CHP

Another option to reduce the total cost of electricity generation could be through Combined Heat and Power (CHP) very near or even in the same place where the consumption is required, or otherwise called decentralized power generation. With this method therefore, transmission and distribution losses of energy are kept low. This method is possible to utilize the heat that otherwise would be lost pointlessly and even at the expense of the environment. In the case of Nisyros the extra heat generated could be used in desalination or in a district heating system, since the distance scale between production and consumption is very small. Regarding fuel that can be used with this technology, there is no particular restriction, making biomass and biofuels eligible (CRES), which can be cultivated and produced in the area of Nisyros and become a development driver for the local community (development of biomass farming). Thus, the CHP, due to its decentralized nature can contribute to economic development of the island, while helping to reduce unemployment (EC, 2008a). Regarding the case of the use of cogeneration for district heating, a very important parameter is the safety provided in transportation and use, which could be considered higher than that of Natural Gas or even electricity.

The technologies currently available and widely used nowadays for cogeneration are (EDUCOGEN [9],ESC and DOE [10]; Frangopoulos etc. [11], CRES [12]):

- reciprocating engines,
- micro-turbines,
- gas turbines,
- fuel cells,
- steam turbines,
- steam turbines and Rankine bottoming cycles
- Organic Rankine cycles, using organic compounds instead of water at lower temperatures.

Table 2 presents technical and economic characteristics of the various systems of decentralized generation and cogeneration.

Table 2. Technical and economic characteristics of the various systems of decentralized generation and cogeneration

Technology	Sector	Typical power (MW)	El. Production Net Efficiency	CHP Net Efficiency	Installation Cost ($ 2005/KW)	Lifetime (Years)
Fuel Cells	Residential	10	0.32	0.699	$ 6,199	20
Fuel Cells	Commercial	200	0.44	0.66	$ 6,219	20
NG ICE	Commercial	300	0.32	0.78	$1,878	20
Oil ICE	Commercial	300	0.34	0.74	$2,268	20

For these calculations a turbine height of 100m (hub) and a capacity factor of 35% have been assumed.

The Hywind turbine was installed by companies StatoilHydro and Siemens at a 220m depth and at a 12km distance away from the coast in Norway. More information on this will be reported below.

5. Comparative economic data for Installation/Operation/Maintenance of RES

i. Wind Power

Almost 75% of the total cost of the produced energy from a wind generator relates to the initial installation cost – such as the cost of generator, civil engineer costs, electrical installation and connection to the grid [16]. Table 3 presents the cost breakdown for the installation of a typical 2MW Wind Generator.

Table 3. Cost breakdown for wind generator installation

	INVESTMENT COST (€1,000/MW)	INVESTMENT COST ALLOCATION %
GENERATOR	928	75,6
CONNECTION TO THE GRID	109	8,9
FOUNDATION COST	80	6,5
LAND OWNERSHIP	48	3,9
ELECTRICAL INSTALLATION	18	1,5
CONSULTANT COST	15	1,2
OTHER COST	15	1,2
ROAD CONSTRUCTION	11	0,9
CONTROL SYSTEMS/AUTOMATION	4	0,3
TOTAL	1,227	100

Note: Costs are calculated based on data provided by European Wind Energy Association (EWEA)

Maintenance and operational costs of onshore wind parks, are calculated to be around 0.3-0.4 cents of Euro (c€) per kWh of produced energy for the first two years in operation – which are usually covered by the manufacturer warranty – while they rise to 0.6-0.7 (c€) after six years. Data from EWEA indicate that less than 60% of the cost, is for the generator maintenance, while the rest 40% is equally distributed between operational and spare parts cost.

ii. Photovoltaic Parks

The investment cost for a photovoltaic park depends on the technology used in each occasion and can reach up to 5000 €/KW. The advantage of this specific technology is that despite the high installation cost, the maintenance and installation costs are significantly less (almost zero) in comparison with other conventional installations, and with other RES. Moreover, the development and utilization of more efficient materials in photovoltaic panels, creates an even more attractive cost/benefit ratio.

iii. Geothermal plants

The commercial viability of Geothermal plants for the production of electrical energy (exploitation of high enthalpy geothermal fields); is influenced by the high cost for land ownership, plant installation, drilling costs (which usually have a high accident risk – gas leakage, possible increase of seismic activity) - and operational and maintenance costs. The risks during the investigations period as well as the high maintenance cost have been documented in previous work of the authors. Briefly, it is the quality of geothermal fluids which plays an important role to the increase of maintenance and operational costs of a geothermal power plant.

More specifically, the analysis of the geothermal fluid (brine) of Nisyros, has shown that it is a very corrosive mixture of heavy metals, residues of rock formations and dissolved gases such as methane, hydrogen sulfide etc. making the maintenance and cost of spare parts quite expensive. The composition of the Nisyros geothermal fluid has an impact to the operational cost, since the cost for brine treatment must be taken into account before its disposal in the sea.

Indicatively, an initial investment cost/kWh for a geothermal plan of average capacity (5-30MW), ranges between 2000€-3000€ [17]. The operational and maintenance costs range between 0.3(c€) – 1.03 (c€).

6. Mild exploitation of the Geothermal Field of Nisyros

In order to utilize the rich geothermal field of Nisyros and avoid any consequences - as these have been described in previous work of the authors – its utilization for domestic heating and cooling is proposed. Geothermal energy of low enthalpy is used for many years with safety and good operation guarantees, in large scale residential heating of many countries as Ireland, Japan, New Zealand and Russia. The same operational scenario can be implemented in Nisyros, by exploiting only the geothermal fluids of low enthalpy for power production. Regarding Nisyros and according to climate conditions, it is calculated that the geothermal energy can be used during 150 winter days for heating and during another 150 days for cooling by utilizing absorption systems.

The excessive heat produced can be utilized for a number of other applications, except for the production of electrical energy, a fact that could give an important push to the local economy. Such applications are drying of agricultural products (140 ^{o}C), canning (140 ^{o}C), production of fresh water by distillation (120 ^{o}C), usage of hot water in the existing desalination plant (120 ^{o}C), greenhouse heating (80 ^{o}C), greenhouse heating by radial pipe network (30 ^{o}C), aquacultures (20 ^{o}C), mushroom cultivation and baths (50 ^{o}C) [12, 13]. Certain special morphological characteristics and features of Nisyros (e.g. lack of relatively deep gulfs for aquacultures), make some of the aforementioned practices impossible to implement.

In the case of greenhouses, the cost of heating with conventional methods can be up to 20% of the product prices. Finally, geothermal energy can be used in animal breeding, for the heating of the installations of milk production and animal breeding, even though the great distances of the island from the industrial centers in the mainland, make such ventures almost economically unfeasible.

7. RES case studies in Nisyros Island

The aforementioned RES case studies for power production in order to cover the power demand of Nisyros, as this is presented in figure 3, are studied through techno-economical analysis using real data in the commercial program RetScreen [14].

The basic study axes of the following scenarios include the systems for power production that are analyzed, in order to cover the base load and the peak load. In order for this study to analyze a complex combination of systems for covering the necessary energy, the load curve for each day or even hour should be available. Due to the fact that this was not possible, the scenarios developed are set in order to cover the monthly load demands (MW). Therefore two different scenarios for RES installation are studied (wind generator and photovoltaic) along with an ICE. This is done in order to either ensure the cost effectiveness of the grid (1st scenario), or for greater safety, to guarantee power production in case that the dominant north/north-west wind does not blow and/or there is no sunshine (2nd scenario). However, the second scenario is covered at the expense of cost efficiency. In each case, every secure system provides the installation of an ICE, capable of covering the maximum load needed, even in the worst-case scenario, which is no power production from RES (cloudy and apnea). Moreover if ICE is combined with CHP, a short response time of the system to load variances can be ensured, and particularly in the case of Nisyros, the desalination plant can be used as a reservoir for storing excess power as heat.

In the first scenario, the installation of a high capacity Wind Park is studied, by considering the islands Kos-Nisyros-Tilos as a grid where the produced power in Nisyros will be transferred for covering the needs. It must be noted that the mean power of 2,3 MW generated, as proposed, is lower than the 30% of the peak load of consumption of the investigated grid (Kos-Nisyros-Tilos), as required.

In the second scenario, the case of installing a wind generator, photovoltaics and ICE for securing the power production is studied. In this case Nisyros is regarded as a stand-alone system without being connected to a grid with the rest of the islands. This system can be considered secure and capable of covering the entire load needs of Nisyros, but not economically efficient. In the following figure (figure 3) the average monthly consumption of Nisyros is given:

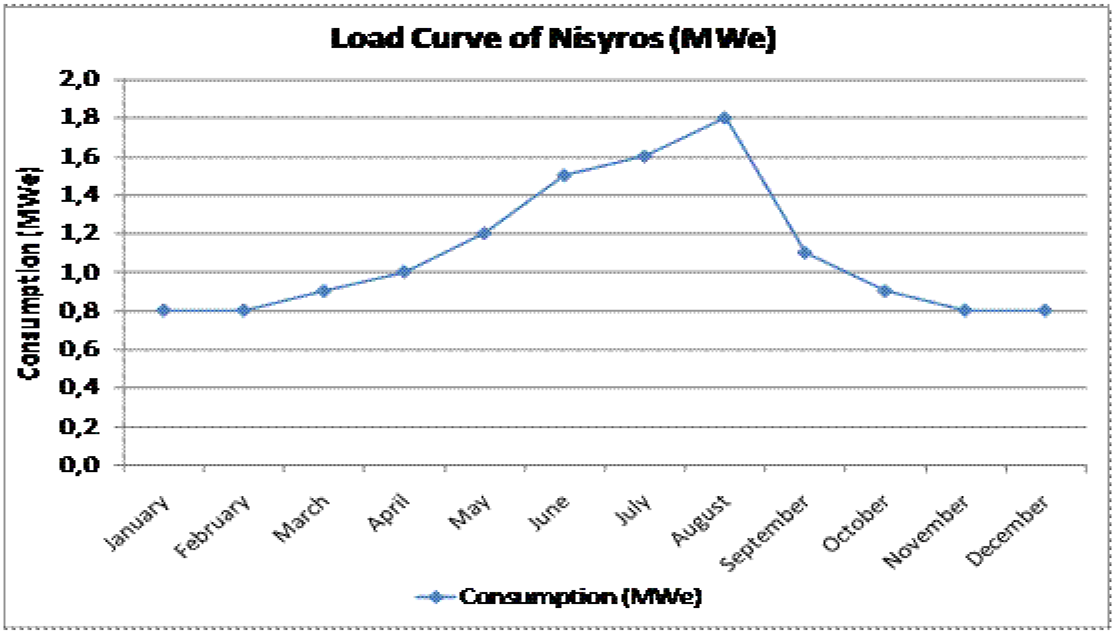

Figure 3. Load curve of mean monthly consumption of Nisyros island

1st Scenario:

The first scenario is the installation of four wind generators of 2,3MW nominal power output. The capacity factor is about 20%, so as according to wind rose of Nisyros (for 10m height the average wind speed is 5m/s) and for an average wind speed of 6,5 m/s, the power generated from each wind generator to be about 600kW.

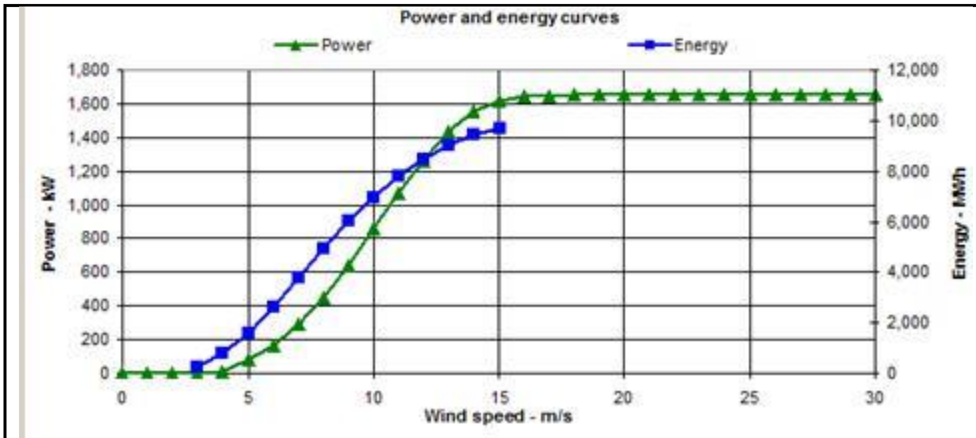

Figure 4. Power and Energy curves for the chosen wind generator type

Installation costs of the wind turbines is about 8.300.000€, by taking into consideration an average market cost of 900€ per kW and a total maintenance cost of about 1.000.000€. Taking into account a 3% inflation rate, 25 years lifetime, 35% load on basis of debt ratio, bank interest rate of 5.8% and a repayment period of 15 years, it is calculated that the payback period of the investment is 2.5 years. This time is less than a typical of 7 years, due to the economy of scale. Afterwards the profits are continuously increasing. For this to happen, it is considered that the investment is financed at a percentage of 40% from the Greek state and EU since it significantly contributes in the reduction of CO_2 footprint while the income from selling each MWh is 99,45 € (RAE, Regulatory Authority for Energy [15]). It must be noted that the investor's income is solely from selling electricity to the grid and not from CO_2 reduction, since the project is funded. The internal rate of return (IRR) for this system is calculated to be 41.9% making the investment very favorable. The cumulative cash flows are given in figure 5.

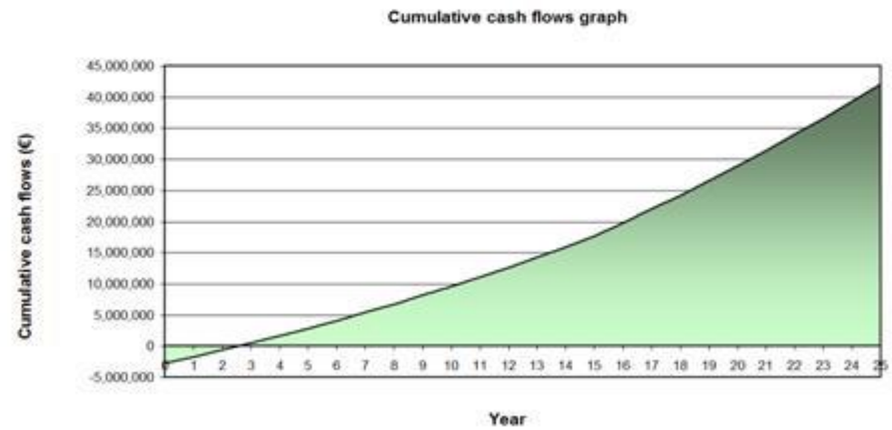

Figure 5. Cumulative cash flows for the 1st scenario

2nd Scenario:

The second scenario includes the initial installation of two Wind Generators of total nominal power output of 2600 kW, at a cost of 2.300.000€ with a 25% capacity factor (increased by 5% compared to the previous scenario due to lower power). For a mean wind speed of 6.5 m/s, each wind generator produces 350 kW. Afterwards a PV system is added with a 1200kW nominal power, a cost of 8.500.000€ and a 17% capacity factor. Therefore, the average power output is equal to 200kW, which is added to the aforementioned 650kW.

The required installation surface of the photovoltaic park is about 10,250 m^2. In order to ensure system security and to meet the needs for power without excessive costs, a 2250 kW nominal power Diesel ICE is added for the extra power required, while the excess energy produced will be transferred to the grid. The sizing of the ICE is done to completely cover the required load of the island, under the most unfavorable conditions (apnea, cloudy and very high demand in summer). The advantage of this scenario compared to the first is the security it provides, since it exploits more renewable energy sources (wind and solar).

Taking into consideration the same economic parameters as in the first scenario, but considering that the selling price of each MWh generated is 457 € for photovoltaic modules in non-interconnected islands (RAE [15]), it is estimated that the payback period is 7 years for photovoltaics and 4.5 years for the wind generator (see Annex).

The downside of this scenario compared to the first one is connected with the existence of ICE, which costs about 1.700.000 € and has average operating costs of 0.6 € per diesel liter that is consumed, which is about 650.000 € per year considering that ICE operation corresponds to 4600 h per year (50% of the year). Considering the same economic parameters as above, the resulting cash flow curve shows that the cost increases linearly each year, with the price of 50,000,000 Euros in the 25th year. Summing the cash flow curves for the three different systems described, in 25 years the loss of the investment will be about 34.000.000 € (7.000.000 € profit wind generator and 9.0000.000 € photovoltaics). This shows how high the cost of running an ICE (at present) for the Greek economy and that will soon be turning towards the use of renewable energy found all over Greece.

Reminding, we point out that the substation of Nisyros - which is currently inactive - hosts four ICE (three MAN and a DEUTZ)of 600KW total power, which covered much of the island's load before it interconnected with Tilos. One possible reactivation will reduce the initial cost of investment in ICE but would not have any positive impact on operating costs over time.

In the Annex the corresponding calculation details for two scenarios studied are attached.

8. Conclusion

Taking into consideration all of the above, it is concluded that the use of RES for Nisyros is not only feasible, but also has many benefits, both in an environmental and socio-economic level. It is a fact that the economy of Nisyros is now very close to a turning point. The long-lasting support from the mine LAVA S.A. in Gyali, who plays the role of the primary sponsor, shows - with the influence of the crisis prevailing in the global economy – to be reeling and unable to support the major employer on the island, the Municipality of Nisyros. Therefore, a new economic model should be investigated for the island based on two pillars: tourism and business benefits arising from the exploitation of RES. Wind and solar energy that is abundant in the islands of Greece can be used for the benefit of residents, local and national economy without environmentally impacting the region using RES, such as high enthalpy geothermal energy, in ways that have been described in detail in a previous article.

The brief reference on the potential for growth presented by the exploitation of low enthalpy geothermal energy shows the way for an alternative development of animal breeding, agriculture (organic farming development) and tourism. The reopening of the spas on the island, which were the island's base economic factor for many years, is based on mild exploitation of geothermal resources. Such a kind of design would significantly contribute in sustainable development, while providing a real alternative to the dilemma of the exploitation of geothermal energy for electricity generation and all the risks that this involves.

ANNEX

The scenarios are attached as separate files in pdf format.

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