ΙΝΣΤΙΤΟΥΤΟ ΕΝΕΡΓΕΙΑΣ
ΝΟΤΙΟΑΝΑΤΟΛΙΚΗΣ ΕΥΡΩΠΗΣ

"Energy Transition of the Island of Kastellorizo"

IENE STUDY (M. 45)

Executive Summary

In Greece, at the end of 2018, there were 29 Non-Interconnected Island (NII) power systems in operation, where electricity supply is primarily oil-based. The increased cost of power generation of the NIIs, which is passed on to all consumers as services of general interest (SGI), as well as the high greenhouse gas emissions of their system operation necessitate a radical change in the energy system of NIIs. Kastellorizo island with a population of 492 permanent residents (2018) and high tourist activity during the summer season (May - September) is one of the most energy-intensive NIIs which are not expected to be connected with the mainland electricity system. Therefore, this preliminary study of IENE is focused on the energy transition of the island, covering all energy needs of consumers and the economic activities during the year by clean and affordable energy. In addition, the island complex of Kastellorizo, which has been inhabited for more than 2,500 years continuously with a population of Greek origin, has enormous geo-strategic importance for the country, since both its geographical location and the economic activity of its inhabitants have a direct impact on the delimitation of Greece's Exclusive Economic Zone (EEZ).

The existing energy system of Kastellorizo (Megisti)

Today, Megisti's autonomous electricity system is oil-based with the local power generation station maintaining seven (7) diesel generating units with a total installed capacity of 1.45 MW. Electricity is generated at a very high cost and with significant emissions of greenhouse gases and particulate pollutants, with an average annual variable production cost amounting to 247.98 € / MWh (2017) due to the high specific cost of oil, while the annual CO_2 emissions amount to 2.926.45 tonnes / year. Kastellorizo's total electricity generation costs in 2017 was € 1,671,500, i.e. € 464.82 /MWh, for a total power generation of 3,596 MWh.

Although efforts have been made to implement energy-saving measures by residents, the currently applied legislation aiming at protecting the traditional character of local settlements acts as deterrent to reconstructive interventions on building shells and solar thermal installations. However, there is a high potential for energy efficiency improvement by installing double glazing, complete replacement of currently installed bulbs with energy efficient ones and installation of solar water heaters wherever possible under the existing legislation. Moreover, the high electrical load requirement for the island's water supply from the local desalination plant is inextricably linked to Kastellorizo's future energy planning.

A New Energy Design for the Island of Kastellorizo

A radical new energy system is proposed for Kastellorizo island, which will incorporate Renewable Energy Sources and energy storage mechanisms. The design of the island's electricity system is based on estimated needs in all sectors (heating, cooling, transport etc.) for a time horizon of the year 2025 with the possibility of expanding in the coming years to meet new energy needs. Important parameters for shaping the island's electricity demand in the future are the following:

- The electricity demand from new consumers
- The increase of electricity demand from existing consumers with new needs.

- The increase of water consumption resulting in increased electricity demand for desalination.
- The energy saving applications expected by 2025.
- The electricity demand for electric mobility expected by 2025.

Taking into account the design parameters, the following estimates were made for electricity demand:

1. Demand for electricity from existing consumers is projected to grow at an average annual growth rate of 2% by 2025
2. Desalination energy consumption was set at 4.5 kWh / m^3 and estimates were made for increasing water demand in 2025 to reach 111,250 m3 / year.
3. Energy saving measures can offset new demand from additional new consumers.
4. Energy savings by energy efficient lighting can offset the new energy demand for electric vehicles deployed for local road and marine transport

Based on the above, the island's electricity demand was estimated at 4.723 MWh / year (2025), with the maximum and minimum hourly demand approaching 1.092 MWh and 0.287 MWh respectively, while the annual peak load is estimated to be approximately 1.13 MW.

The Design of the Power System

Technology: The design of the electrical system of Kastellorizo island focuses on the utilization of the solar and wind potential. The available wind (6.5 - 7.5 m/s average annual wind speed at 100 meters height above ground level) and solar potential (global horizontal irradiance: 1,926 kWh / m^2 / year) favour their use, while due to their intermittent generation, a lithium battery storage system is chosen to ensure reliability and security of power supply and utilization of excess generation. The technologies for RES systems selected are: (a) high performance monocrystalline silicon photovoltaics and (b) high-performance wind turbines with no gearbox with full power output control (Reference Technology: EWT: DW54 250 kW), suitable for medium and low wind potential (IEC IIIA).

The energy storage technology refers to lithium-ion batteries (chemical composition of the battery elements examined are NMC, LFP and LTO) with a battery management system to ensure high performance, low cycling degradation of the battery cells and optimal utilization of the battery system's storage capability while in operation. Suitable bidirectional inverters are used to couple the batteries to the generating units to cover demand.

The Photovoltaic power generation was estimated on the basis of hourly data derived from the JRC European Commission Photovoltaic Geographic Information System (PVGIS) and consist data of a typical meteorological year for the Kastellorizo region using as reference the period 2007 - 2016. The windpower generation for the region was estimated by adapting a ten-minute interval time series of wind speed measurements from a 10 m high measuring station performed by the Center of Renewable Energy Sources (CRES) in Rhodes during the period 1999 -2000 to the average wind speed of the candidate installation areas (6.5 - 7.5 m/s), data for which derive from Global Wind Atlas. All RES generation time series are deterministic and present the average estimated generation during a year, without taking into account the stochasticity of RES.

Design of RES System for Power Generation: Initially, 11 scenarios were created for the capacity of RES units, namely wind turbines and photovoltaic stations, from which the predominant was selected based on the following criteria:

(a) The size of the energy deficit (or the ratio of demand coverage)
(b) The number of hours during which an energy deficit occurs
(c) The number of days during which an energy deficit occurs
(d) The maximum hourly and daily energy deficit
(e) The excess (curtailment) energy generated by the RES system annually
(f) The penetration of RES in electricity generation annually

The spatial arrangement of the power generating units is characterized by the innovative idea of utilizing the adjacent uninhabited Stroggili island, with expected higher wind potential, in order to vitalize the easternmost tip of Greek territory.

The selected scenario for the RES generating units includes:

Wind Turbines: (a) 2 x DWE 250kW installed at a location with an annual average wind speed of 7.5 m / s (Stroggili) (b) 1 x DWE 250kW installed at a location with an annual average wind speed of 6.5 m / s (Kastellorizo).

Solar PV: (a) 800 kWp monocrystalline PV on a 31° tilt angle from horizontal (annuity optimal) (b) 500 kWp monocrystalline PV on a 55° tilt angle from horizontal (winter season optimal) (c) 1,000 kWp monocrystalline PV with seasonal manual tilt adjustment to horizontal level (October - March: 55 °, April - September: 31 °)

Table E1: Power Generation and Excess Energy generated by the RES system of the selected Scenario

Month	Power Generation from Solar PV [MWh]	Power Generation from Wind Turbines [MWh]	Electricity Demand [MWh]	Excess (Dumped) Energy [MWh]	Excess (Dumped) Energy [%]	Utilized Power Generation from RES [MWh]	RES Penetration [%]
Jan	221.31	363.35	375.35	281.36	48.12%	303.3	80.80%
Feb	227.44	315.06	313.22	293.1	54.03%	249.4	79.63%
Mar	326.42	313.99	319.71	388.19	60.62%	252.22	78.89%
Apr	363.77	282.94	299.57	408.77	63.21%	237.95	79.43%
May	365.48	370.73	315.8	450.53	61.20%	285.68	90.46%
Jun	374.04	456.25	403.76	435.58	52.46%	394.7	97.76%
Jul	391.11	422.95	598.03	300.31	36.89%	513.74	85.91%
Aug	393.26	493.27	624.85	325.73	36.74%	560.8	89.75%
Sep	388.88	357.47	471.77	352.23	47.19%	394.12	83.54%
Oct	328.32	330.48	357.05	365.09	55.42%	293.71	82.26%
Nov	286.78	256.46	308.97	306.86	56.49%	236.37	76.50%
Dec	215.48	202.17	334.6	211.37	50.61%	206.27	61.65%
Annual	**3882.28**	**4165.13**	**4722.68**	**4119.13**	**51.19%**	**3928.27**	**83.18%**

Table E2 Energy Deficit of the selected RES system Scenario (for a yearly period: 8760 hours)

Month	Energy Deficit [MWh]	Energy Deficit [%]	Number of days with Energy Deficit	Number of hours with Energy Deficit	Maximum Hourly Energy Deficit [kWh/h]	Maximum Daily Energy Deficit [MWh]
Jan	72.06	19.20%	6	231	632.41	10.09
Feb	63.81	20.37%	5	191	597.30	7.25
Mar	67.49	21.11%	2	228	593.97	5.81
Apr	61.62	20.57%	1	222	493.40	1.51
May	30.12	9.54%	0	136	521.49	0.00
Jun	9.06	2.24%	0	75	363.35	0.00
Jul	84.29	14.09%	4	330	932.46	5.05
Aug	64.06	10.25%	0	347	852.46	0.00
Sep	77.65	16.46%	4	243	904.69	2.81
Oct	63.34	17.74%	0	220	543.74	0.00
Nov	72.59	23.50%	1	297	577.30	2.22
Dec	128.33	38.35%	9	378	597.30	7.10
Annual	**794.41**	**16.82%**	**32**	**2898**	**932.46**	**10.09**

Indicatively, the RES generation of the selected scenario as well as the demand coverage for the month of January are presented in the following figures E1 and E2:

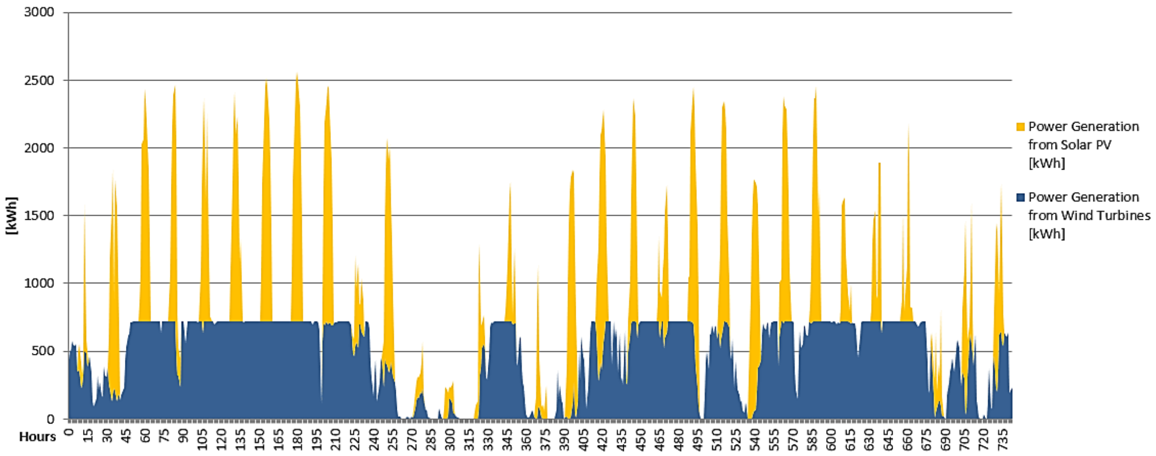

Figure E1: Hourly Power Generation from RES for the selected scenario in January [kWh]

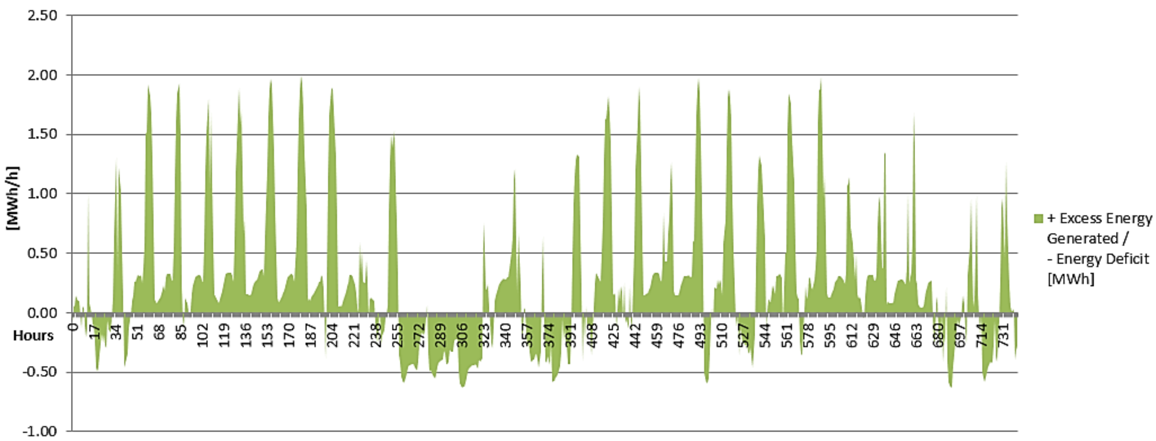

Figure E2: Hourly Power Generation +Surplus/-Deficit for the Power System of Megisti (Kastellorizo) (2025) for the selected scenario in January [MWh]

Dimensioning of the Electricity Storage System: The battery of the electricity storage system was dimensioned using "Bat-Op" (Battery Optimization) model developed by Alexandros Perellis, a Researcher at IENE and Spyros Chatzivasileiadis, Associate Professor at Technical University of Denmark (DTU), which solves the problem of electricity demand coverage as a mixed integer linear problem by optimizing (minimizing) the required installed capacity of a battery system for energy storage, to achieve a particular penetration of RES per month.

The total critical battery capacity, which presents satisfactory RES penetration, based on the results of the "Bat-Op" model was estimated at 4,000 kWh. The difference in meeting the electricity demand with a battery system of such size compared to smaller ones is noticeable mainly in the winter months but also significant throughout the year. Taking into account the average annual diesel consumption of the island's current power station, a system with 4,000 kWh battery capacity will be capable of reducing the generation requirement of diesel power generating units by approximately 72 MWh/year or otherwise to reduce the island's annual need for diesel by about 18 tonnes compared to a corresponding RES system with lower capacity batteries, e.g. at 3,000 kWh. Based on the high distribution of the power system's generating units across the island for increased reliability and resilience, two (2) identical electricity storage systems with power supply capacity of 1MW each and storage capacity of 2,000 kWh each (2x1MW / 2MWh) were selected.

Power System Simulation: The simulation of the selected integrated system was performed with the reverse version of the "Bat-Op" model, which receives the storage capacity and power supply capability of the electricity storage system as input data and simulates the operation of the power system by maximizing the penetration of the RES into the electricity mix.

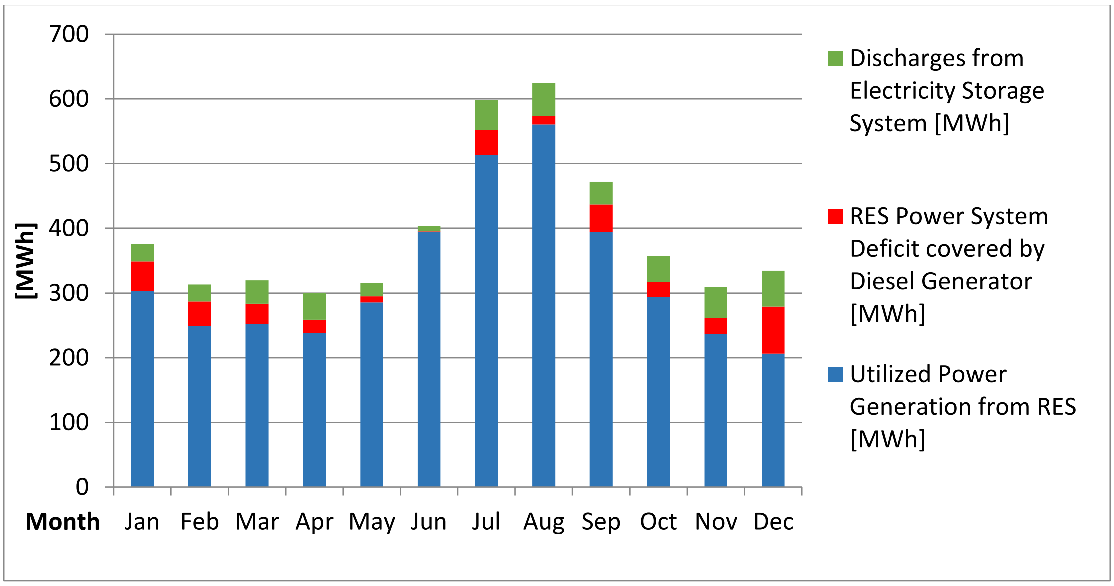

Figure E3: Monthly use of energy resources of Integrated RES - Electricity Storage Power system.

According to the results of the simulation of the system, the integrated RES-Storage power system can achieve 92.36% penetration into the electricity mix of the island of Megisti, utilizing 433.49 MWh of the excess electricity generated by the RES units. This is a significant improvement from the 83.18% achieved by the proposed system without the addition of the electricity storage. The most significant deficits occur in winter due to lack of adequate RES resources.

Table E3: Performance of selected integrated RES – Electricity Storage System per month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Penetration of Diesel Unit in the Electricity mix [%]	12.12 %	12.04 %	9.73%	7.01%	2.95%	0.16%	6.41%	2.05%	9.09%	6.57%	8.24%	21.74 %	**7.64%**
Penetration of RES in the Electricity mix [%]	87.88 %	87.96 %	90.27 %	92.99 %	97.05 %	99.84 %	93.59 %	97.95 %	90.91 %	93.43 %	91.76 %	78.26 %	**92.36%**
Electricity Demand [MWh]	375.3	313.22	319.7	299.57	315.8	403.76	598.0	624.85	471.8	357.05	309.0	334.60	**4722.68**
RES Generation Deficit covered by Backup Diesel Generators [MWh]	45.50	37.70	31.09	21.00	9.33	0.63	38.33	12.81	42.87	23.45	25.46	72.75	**360.92**
Dumped Energy from RES [MWh]	254.8	266.99	351.8	368.15	429.7	427.15	254.3	274.48	317.4	325.21	259.7	155.80	**3685.66**
Utilized Energy from RES [MWh]	303.3	249.40	252.2	237.95	285.7	394.70	513.7	560.80	394.1	293.71	236.4	206.27	**3928.27**
Number of operational hours of Backup Diesel Generators	133	107	100	78	31	6	87	49	101	78	93	210	**1073**
Discharged Electricity from El. Storage System [MWh] (Utilized / After losses)	26.56	26.11	36.40	40.61	20.79	8.43	45.96	51.25	34.78	39.89	47.13	55.57	**433.49**

An illustration of the performance of the integrated RES-Electricity Storage system for January is shown in the following chart E4.

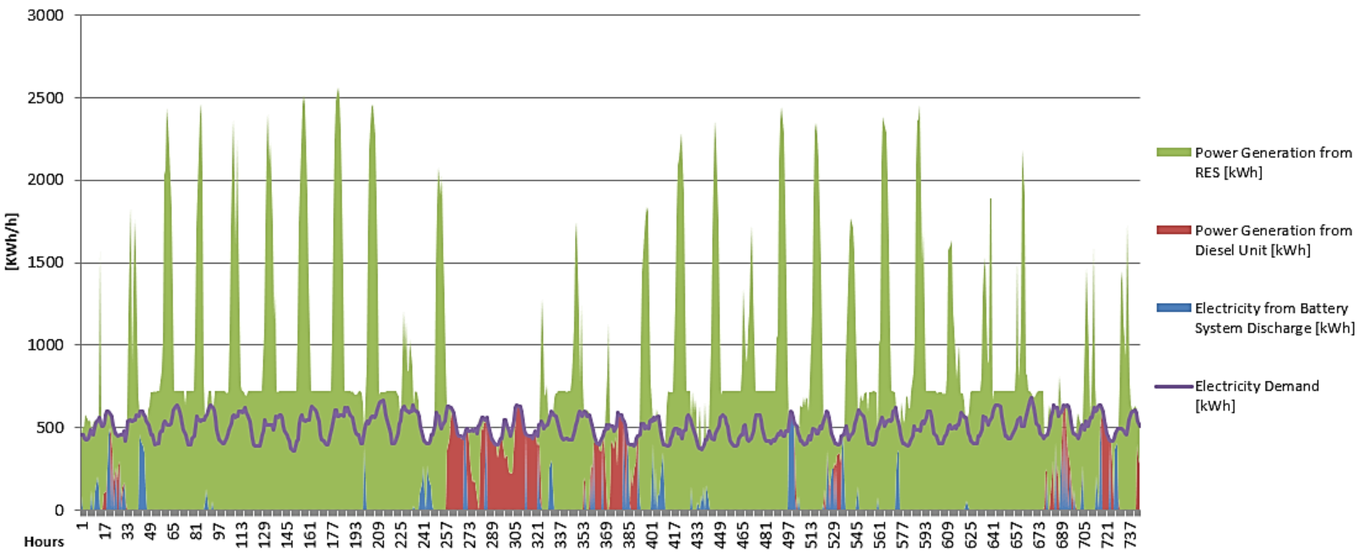

Figure E4: Performance of Integrated RES - Electricity Storage Power Sources for January

Power System Optimizations: A Demand Side Management (DSM) technique aiming at maximizing RES penetration in the electricity mix was implemented in the system by shifting the loads to hours of excess power generation, avoiding the use of backup units (diesel). In particular, the application was performed for electricity demand for water desalination taking into account the technical specifications of the existing desalination units with water storage facilities and the results are shown in Figure E5. It is also proposed that in the future the Demand Side Management technique is extended to other electrical uses (eg. electric water heaters, heating and cooling of buildings, electric vehicle charging etc.), optimizing the operation of the island's energy system.

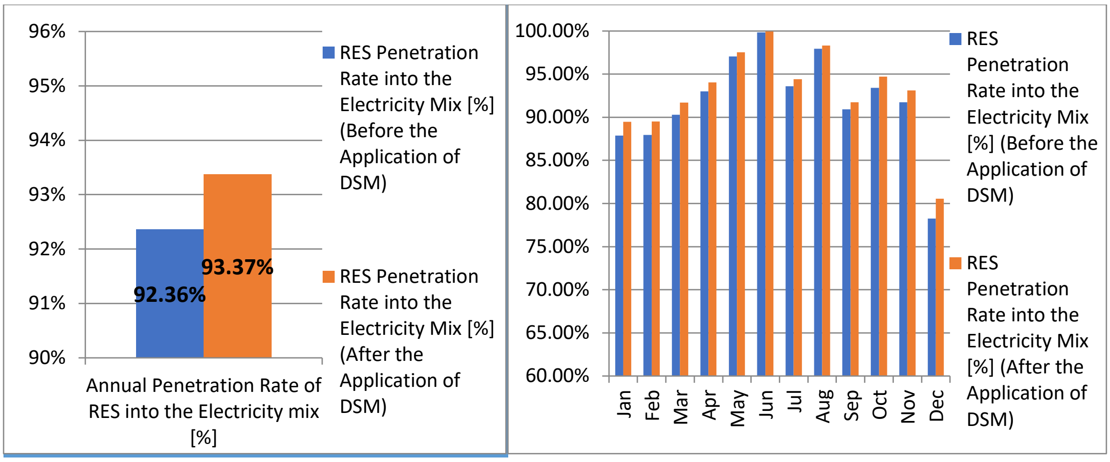

Figure E5: Annual and monthly RES penetration into electricity mix before and after the application of Demand Side Management technique for electricity demand for water desalination.

The electricity demand response with DSM technique for electricity demand for water desalination can increase the utilization of surplus RES by increasing their penetration into the island's electricity mix by approximately one percent (1%) to 93.37%.

Table E4: Monthly and Annual Performance of Integrated RES - Electricity Storage Power System after DSM application

Month	Power Generation from RES [MWh]	RES Generation Deficit covered by Backup Diesel Generators [MWh]	Διείσδυση ΑΠΕ [%]	Χρησιμοποιούμενη ενέργεια ΑΠΕ [MWh]	Ηλεκτρική Ενέργεια Εκφόρτισης [MWh]	Απορριπτόμενη Ενέργεια [MWh]	Απορριπτόμενη Ενέργεια [%]
Jan	584.661	39.5	89.40%	309.3	26.56	249.7	42.71%
Feb	542.5	32.8	89.53%	253.97	26.11	261.47	48.20%
Mar	640.406	26.56	91.69%	256.55	36.4	348.3	54.39%
Apr	646.714	17.86	94.04%	240.99	40.61	363.95	56.28%
May	736.212	7.77	97.54%	287.26	20.79	428.21	58.16%
Jun	830.287	0.25	99.94%	394.7	8.43	427.08	51.44%
Jul	814.055	33.49	94.40%	518.67	45.96	252.21	30.98%
Aug	886.533	10.56	98.31%	562.68	51.25	272.26	30.71%
Sep	746.351	38.94	91.75%	397.87	34.78	312.45	41.86%
Oct	658.804	18.85	94.72%	298.31	39.89	318.67	48.37%
Nov	543.243	21.25	93.12%	240.21	47.13	256.45	47.21%
Dec	417.649	65.08	80.55%	214.44	55.57	147.28	35.26%
Annual	8047.41	312.9	93.37%	3974.95	433.49	3638.03	45.21%

Suggestions for System Design and System Operation:

- The Power System management is based on digital technology and therefore it should be undertaken by appropriate software which will ensure smooth, uninterrupted and efficient operation using: **(a)** advanced forecasting tools for electricity demand and power generation from RES; **(b)** efficient integration of backup generating unit based on the outputs of demand/generation forecasting tools, **(c)** efficient planning of electricity storage system's charging/discharging cycles based on projected demand-generation, **(d)** optimization of the operation of the entire system by applying Demand Side Management (DSM); **(e)** an efficient diagnostics system for RES power plants.

- It is proposed to use diesel backup generators efficiently (2 x 500kW / 600kVA) in order to cover deficits from intermittent RES generation and charging the electricity storage system with a limited number of startups per year.
- It is proposed to maximize the penetration of RES into the local electricity generation by strengthening the synergies of all available RES and by future applications aiming for extensive use of inter-seasonal energy storage with new technologies.

Power System Synthesis: The Power System Synthesis was investigated under the following energy planning criteria:
(a) The distributed generation of various RES generating units in distance from each other aiming for higher security, resilience and flexibility of the Power System.
(b) The enhanced security of the Power System is achieved with the installation of two identical control centers for the automated management of the system.
(c) The installation of distributed electricity storage systems (using two (2) identical storage systems is proposed for Kastellorizo's Power System)
(d) Adaptation of generating units' output to electricity demand with appropriate and efficient management tools.
(e) Extension of the medium voltage network to create a closed loop, where the power generation units and storage systems are connected, along with substations for the consumers.

Suggestions for System Control and Protection: It is obvious that in a microgrid based on power electronics, such as the one proposed for the island of Kastellorizo, the problem of network and consumer protection against overvoltage events, created mainly by short-circuits between the phases and the earth, cannot be addressed by applying widely utilized thermal fuses and overcurrent relays. This is because electronic inverters are not capable of providing instantaneous high electrical current to address short circuits due to the fact that the moment of inertia of rotating conventional generators, which provides stability to the electrical system even in the event of a disturbance, is lacking in such systems. Both bi-directional inverters and electricity storage with adequate software can provide excellent ancillary services to counteract system failures (generator loss, load loss, etc.) as well as anomalies (short circuits) occurring in the low voltage distribution network in synergy with conventional protections, but for the Medium Voltage (MV) network the system requires special measures. To address the protection in overvoltage events in the MV network it is recommended to foresee:

- The installation of a rotating capacitor, a modern load-free unit, in the system that operates continuously in synergy with power electronics and is capable of providing instantaneous short-circuit current to neutralize the network faults.
- Another new solution based on modern ICT technologies and decentralized intelligence that can be implemented in the medium voltage network. The error is first detected in the data arriving at an AI control device (with very short response times), which after processing the data commands the opening of the corresponding switch that isolates the network fault.
- Ultimately, a complete solution is the introduction of complete digital technology to the distribution network that ensures better operation and effective protection, contributing to better load management in collaboration with consumers for optimal results and mutual benefits.

Proposals for Power System's Spatial Design: Kastellorizo's new electricity system in order to provide consumers with high-quality uninterrupted power supply is proposed to be spatially distributed in such a way that power generation and electricity storage will be equally distributed across the medium voltage network, which will be forming a closed loop with two interchangeable control systems. In addition, wind turbines will be installed on locations with an estimated high wind potential under strict consideration of environmental restrictions, while Solar PV stations will be placed in selected public areas outside the settlement, where their environmental integration will not be challenged.

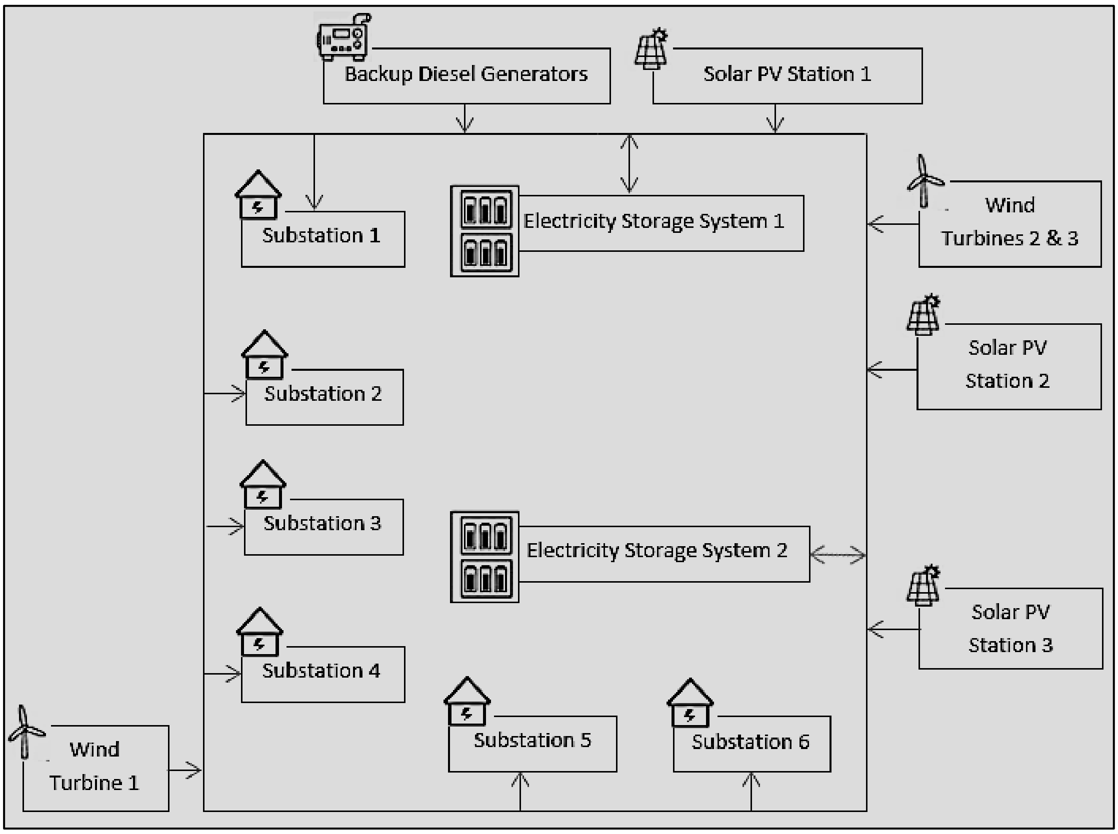

Figure E6: Monogram diagram of the new Power System of Kastellorizo island

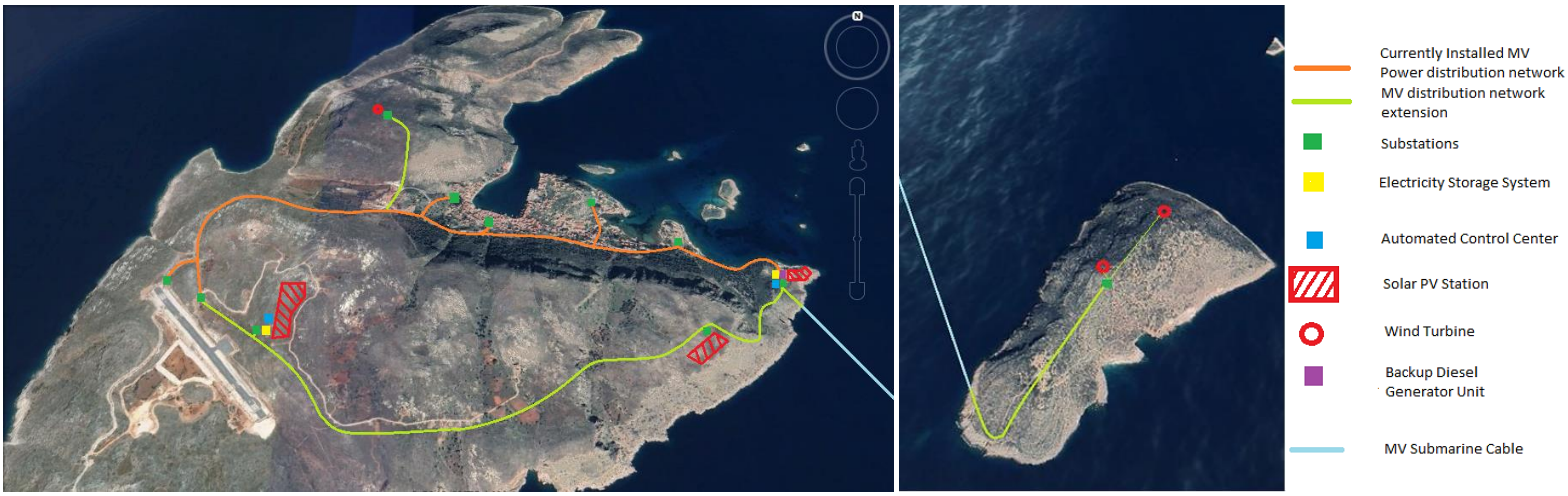

Figure E7: The new integrated RES-Electricity Storage System at the proposed installation sites and the geographical map of the island's micro-grid loop

Specifically, three Solar PV stations on the island of Megisti (Kastellorizo) at locations Pefkakia (300 kWp) (where the PPC power station is currently located), Avlonia (700 kWp) and Vigla (1000 kWp) and three wind turbines (250 kW each) are proposed; one on the island of Megisti (Kastellorizo) at location Mounta and the other two on the island of Stroggili, interconnected with a submarine cable with the power system of Kastellorizo. In addition, the current study takes into account consumer participation in electricity generation with 300 kWp of household PV. In addition, the installation of two Electricity Storage units is proposed, which will be composed by li-ion batteries (2 X 2 MWh and 2 X 1MW) and will be installed (a) at the PPC power station site (Pefkakia), where the 1st photovoltaic station (300 kWp) will be located and (b) at Vigla location, where the 3rd photovoltaic unit (1 MWp) will be located, to provide security of supply in case of system failure. Also, to achieve resilience in Kastellorizo's power system, two automatic control centers are proposed at the ends of the grid's loop at the locations where the electricity storage systems are located: (a) Pefkakia location, (b) Vigla location.

Cost Analysis and Investment Evaluation

The cost analysis was carried out by estimating the individual costs of the equipment and works taking into account the current literature and estimates by domestic and international market players. Capital and operational expenditure of the investment are presented in Tables E4 and E5 respectively.

Table E5: Investment's Capital Expenditure (CAPEX) (€)

Generating Units	*Final Cost (€)*
Solar PV Parks (2.300 kWp)	2,290,000
Wind Turbines (750 kW)	1,182,500
Electricity Storage Systems with li-ion batteries (2 X 2 MWh/1 MW)	1,200,000
Energy Management System and Backup Diesel Generators (2 X 500 kW/600 KVA)	850,000
Capital Expenditure (CAPEX) (€)	**5,522,500 €**
Capital Expenditure (CAPEX) (€) (Including battery pack substitution cost in 2038)	**6,122,500 €**

Table E6: Total Annual Operational Expenditure (OPEX) for the new integrated power system of Megisti island (€)

Annual Variable Operational Costs (OPEX)	*Final cost (€)*
Purchase of fuel (diesel) for Backup Diesel Generators (82.940 lt)	67,140
Rental of PPC's facilities	12,000
Staff cost (2 employees)	60,000
Maintenance costs for Solar PV Stations	40,100
Maintenance costs for Wind Turbines	90,000
Maintenance costs of Electricity Storage Systems (€/€ CAPEX)	24,000
System's Fixed Operational Expenses (2025 -2049) (€/year)	**226,100 €**
System's Variable Operational Expenses (2025 -2049) (€/year)	**67,140 €**
System's Total Operational Expenses (OPEX) (2025) (€)	**293,240 €**

The investment was evaluated using the levelized cost of investment, LCOE, for which a number of assumptions were made, the most important of which are: **(a)** the full coverage of demand load by the proposed system; **(b)** the residual value was considered to be 0% for generating units and 20% for battery cells; **(c)** decrease in photovoltaic efficiency cannot affect demand coverage; **(d)** decrease in battery capacity may not affect their smooth operation (covered by limited depth of discharge: 70%); **(e)** inflation and loan costs (interest) are not included in the calculation but a weighted average cost of capital (WACC: 4%) was taken into consideration; **(f)** investment duration is assumed to be 25 years .

The Levelized Cost of Electricity, LCOE (€ / MWh) of the island's power system for the baseline scenario was estimated at **148.72 €/MWh**. The annual cost of the investment, ie. the annual cost of the system if we set fixed annual payments throughout the investment's lifetime (payment in an ordinary annuity) amounts to **679,637 €/year**.

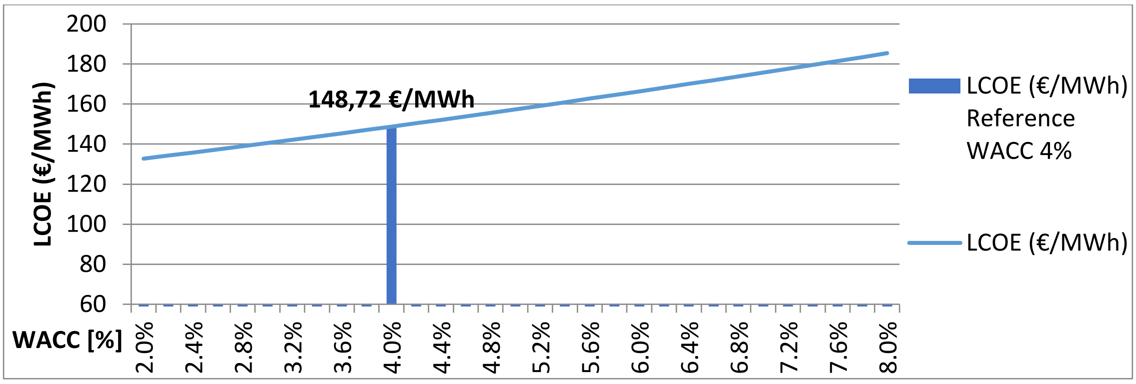

Figure E8: Sensitivity Analysis of the weighted average cost of investment capital (WACC) on the LCOE for the proposed Power System of Kastellorizo island.

Therefore, the proposed RES – Electricity Storage Power System has the potential to reduce the cost of electricity of the island of Kastellorizo by 3.25 times in comparison to what it was in 2018 (483.44 € / MWh), and by 3.03 times in comparison to the average realized power generation cost for the five-year period of 2014-2018 (€ 451.15 / MWh). Indicatively, taking into account the difference in power generation costs (483.44 -148.72 = 334.72 € / MWh) the total annual benefit may amount to € 1.509.520 for the anticipated generation of 2025, reducing the SGI cost by 1.5 € million per year (indicative).

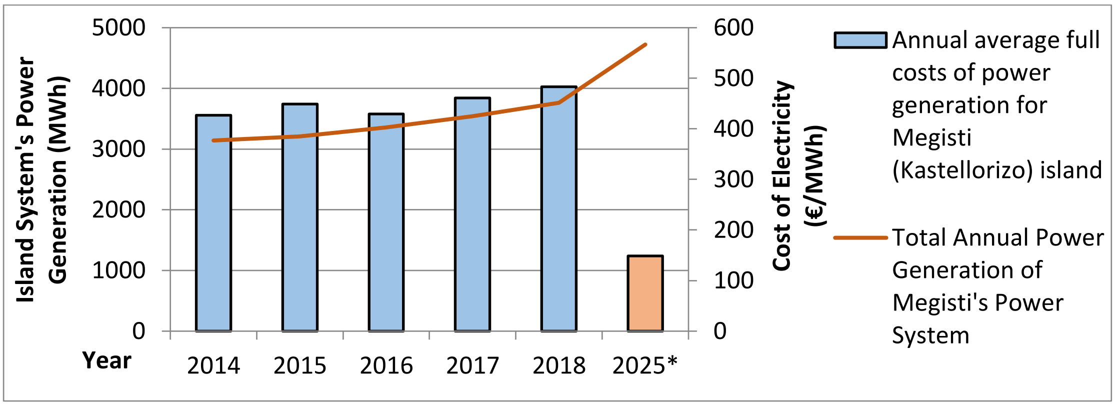

Figure E9: Comparison of the average full cost of power generation for the current power station of Megisti (Kastellorizo) for the years 2014-2018 with the levelized cost of electricity (LCOE) * of the proposed integrated RES-Electricity Storage Power System for 2025.

A New Regulatory Framework for Non-Interconnected Islands is required

The current regulatory framework for power generation on the non-interconnected islands does not facilitate the deployment of RES-based microgrids as integrated power systems aiming at island self-sufficiency. As a result, the electricity mix on the non-interconnected islands is oil-based with all the implications that come with it. Therefore, immediate action is needed to address the problem. Consequently, the study raises several issues and proposes a number of measures that need to be initiated, the most important of which are:

- The assignment and preparation of specific preliminary studies for each Non-Interconnected Island (NII) to be assigned by the Regulatory Authority for Energy (RAE) with HEDNO's contribution.
- Power generation by the proposed systems in the reference studies cover all energy needs of the islands with a medium-term demand horizon having electricity as the main energy carrier and the target of RES penetration set at a specific high percentage, i.e. at 70% or 90%.
- Each study to cover desalination / water supply, transport (electric cars), heating and cooling of buildings requirements and in general address all energy needs over a medium term, which correspond to the local conditions and economic activities of each island.
- In the design of the new energy systems the principles of Microgrid, techniques and ideas should be adopted for high resilience and reliability of the integrated power system in various situations, introducing digital technology to distribution networks.
- These preliminary studies should also propose locations for the installation of wind turbines, PV stations and energy storage systems.
- Following acceptance of the preliminary study and the briefing of the authorities and the island's inhabitants, measurements of wind characteristics for the selected sites for one year to be carried out, while environmental permits (wind, photovoltaic, batteries, etc.) are issued.
- Medium voltage power lines should be drawn to connect the grid to the new generation and storage units. These projects will be assigned to HEDNO, the local DSO, also responsible for the existing distribution network on the NIIs.
- Studies for the control and protection of each integrated island power system to be carried out.
- Existing RES generating units in operation must also be considered in the preliminary studies.
- The inhabitants of the island should have the right to install individual solar PV units (up to 5kWp each).
- A development program for solar thermal systems' installation for hot water end-use is to be promoted with specific studies and special incentives.
- Development and implementation of DSM to be applied techniques in cooperation with consumers.
- The utilization of existing power system infrastructure including existing local power stations to be considered (concession by HEDNO)
- The operatory contractor will undertake the necessary investments and operate the entire system with own trained personnel and the appropriate tools for the provision of uninterrupted energy supply.
- The contract with the owner/operator will be awarded following an international tender based on best practice market principles.

- During the contract period, the operator will seek to improve the penetration of RES beyond the set limit for economic benefits in accordance with technical developments.
- The operator must comply with the rules and conditions laid down by international regulations for reliable, uninterrupted and high-quality electricity supply (e.g. relevant IEC standards for microgrids).
- The design and installation of an appropriate metering system and a power generation data processing programme is necessary to be directly accessible by RAE and HEDNO in order to monitor the system's compliance with the relevant and agreed operating conditions.

At the same time, it should be noted that this initiative for the Non-Interconnected Islands will create many new jobs for highly trained and specialized staff and will lead to investments with great economic benefits, contributing in the strengthening of the local economy. The establishment of Energy Communities (as per latest legislation), are expected to further promote the involvement of local operators and consumers in reducing energy costs, while improving the functionality of the energy system (demand response-balancing services, smart meters etc.). Such Energy Communities could play an important role in the energy transition of the NIIs and also increase RES penetration into their electricity mix.

Discussion and Conclusions.

This study describes a plan to solve the basic economic and environmental problem of power generation in Non-Interconnected Islands by ensuring high reliability and resilience, while securing energy supply. In addressing the energy station in a Non – Interconnected island which is Kastellorizo power generation is to be based on 3 main pillars: the main pillars were wind energy, solar energy and li-ion battery-based electricity storage, while promoting an extensive electrification scenario for the island's energy needs. The system selection was designed to meet Kastellorizo's anticipated energy needs and includes all the decision-making steps for the selection of the energy system's generating units.

The levelized cost of electricity for the island of Megisti (Kastellorizo) with the operation of the proposed integrated power system was estimated at **148.72 € / MWh**, 3.25 times lower than the full cost of power generation for the island in 2018 (483.44 € / MWh) and may lead to a reduction of SGPs by € 1.5 million per year, providing an example in solving the high-cost and emissions problems of power generation in the NIIs. Now, starting from Kastellorizo, is the time for energy transition of NIIs to the new smart and clean energy era, with multiple economic, social and environmental benefits.

The implementation of the present study undertaken by IENE, which aims for the energy self sufficiency of the island of Kastellorizo, and hence its transition to a clean fuel environment, should be seen as an important pilot project in view of its far-reaching implications for other non – interconnected islands in Greece and in the Mediterranean. The Greek government should now examine the study's findings and proposals and move accordingly in order to introduce the necessary legislation and develop the appropriate regulatory framework which will allow the required involvements to be made by interested companies and organizations.