Sustainable Energy Transition in Island Systems with substantial RES and Electricity Storage

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Abstract: - A sustainable power system will require an extensive reliance on renewable energy sources (RES). Taking into account the fact that a significant share of RES has already been deployed, either on large or a small scale, today's most crucial issue is their further participation in an extensive and secure power generation expansion to cover the large future energy demand. Although there is the needed capacity of RES that could cover the corresponding demand, the current power system structure and operation emerge limitations, which hold back their further exploitation. The introduction of energy storage systems, such as pump storage and batteries can help the further exploitation of the needed RES by balancing the current load demand and the intermittent power flow of photovoltaics and wind turbines. This paper analyses a recently interconnected island power system operation, as a representative case study, and demonstrates benefits, such as CO2 emissions reduction, and obstacles emerged by ultra-high penetration of RES. This ultra-high share of RES is technically feasible, through strong interconnections and electricity storage systems.

Key-Words: - Energy Planning, Energy Transition, Renewable Energy Sources, CO2, Sustainability, Electricity Storage.

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1 Introduction

Ensuring energy security and reducing energy dependency has been an integral part of the European Union, as it steadily moves towards a sustainable energy transition, through legislative and funding schemes, such as the European Green Deal [1], the Paris Agreement or the latest European Climate Law, where energy-related issues are closely linked to the climate agenda, [2]. Hence, as the EU rethinks its goals of decarbonizing the economy and energy transition, [3], a significant part of this transition is associated with the challenging task of transforming the energy sector, because it is one of the most important emitters of environmental pollutants, [4]. Climate change objectively requires the attainment of sustainability. Thus, reducing too many negative impacts such as CO2 emissions is a way to achieve the energy transition. Energy production and consumption are considered cornerstones for the reduction of greenhouse gas emissions. Nevertheless, reducing the carbon intensity of the energy sector could be achieved through the implementation of measures such as increasing energy efficiency or expanding the use of renewable energy sources, [5].

Thereupon, the transformation of the power systems sector requires the change of existing energy balance as well as the introduction of new technologies and architectures, [6], [7].

Indicatively, advanced renewable energy harvesting technologies are under investigation, more often with an emphasis on solar and wind energy as prime movers, [8], while enhancements to the power grid are also mandated to host massive amounts of such energy sources, [9], [10], [11], which are usually distributed into the grid in contrast to the legacy technology of centralized large power plants. Alternatively, and since the enhancement of the power grid may correspond to an expensive or geographically infeasible task, novel architectures and control methodologies for power systems are investigated in the context of distributed networks and smart grids, whose smart operation can potentially alleviate such bottlenecks, [12], [13], [14].

An additional consideration lies in the electrification of other energy carriers, such as the heating and transportation sectors, to neutralize their footprint, as they are considered important polluters as well (Table 1).

Table 1. Sources of Green House Gas Emissions (C2es.org & Statista.com)

	Emissions (%)	
Sources	2013	2019
Electricity & Heat	31	32
Transportation	15	17
Agriculture	11	12
Manufacturing	12	17

Further development of these sectors is expected to vastly increase the load that the electric power system needs to accommodate. However, energy use produced by non-renewable resources causes carbon dioxide (CO_2) emissions to increase, [15]. And even though a reduction in energy consumption may affect CO_2 emissions, [16], it may also hinder economic growth, [17], [18], as any discussion of changes in CO_2 emissions is interconnected with economic changes, and economic growth, [19]. Hence appropriate policies are needed for energy efficiency like energy security, [20] and sustainability. As the energy security issues attracted the attention of global policymakers, they agreed that energy consumption pattern requires an energy transition, [21], [22]. Thereupon, both smart grids function for effectively managing the power system operation, but also increase renewable energy production for neutralizing the environmental footprint of the energy production process, which are crucial in this context.

According to the above arguments, the increase in renewable energy production in a power system is of crucial importance. Hence, a challenge arises in calculating the hosting capacity (HC) of each area in a power system, so that the amount of renewable energy sources (RES) that can be interconnected is known to the corresponding regulators and operators, [8], [23]. Traditionally, the main reasons limiting the RES hosting capacity have to do with,

i) conventional power plant operation,
ii) thermal and short circuit limitations at the distribution network and
iii) voltage and frequency regulation, [24].

To quantify the above-expressed problem, various techniques have been proposed, with most of them focusing on iterative simulation, [23], while others also consider streamlined and stochastic approaches, [24], [25], [26]. Moreover, as voltage violations are one of the main hosting capacity limitations functions, the capability of voltage-related ancillary services provision by smart inverters has been reviewed in [11], [26]. As it is evident, in most of the projects, the hosting capacity is tackled from the distribution system operation point of view, which of course is reasonable due to the weaker operation of the grid as well as the underlying spatial issues. Nevertheless, important considerations could be also concluded from the transmission system operation point of view. In this regard, [27], discussed the transmission side HC based on transient stability considerations, while short circuit currents have also been discussed in [28], [29]. Moreover, transmission and distribution system co-simulations were performed in [30], to take into consideration the limitations that arise from the transmission system operation.

European Islands, based on the previous statements and considering their geographical and natural position represent a key actor with specific characteristics in the implementation framework of a sustainable energy policy. More precisely, three main dimensions have been identified by the European Commission for successful energy planning, which is security of supply, sustainability, and competitiveness. Furthermore, several obstacles and technical restrictions are evident in an island's energy sector, such as higher total costs, fluctuations in the price, and insecurity of supply. However, these disadvantages can be outweighed by inherent advantages, especially by the utilization of renewable energy technologies, thanks to their relatively high wind and sun exposure, [31]. This potential should be further exploited to investigate the operation and planning limitations and estimate the possible solutions, [32].

2 Materials and Methods

Renewable energy sources for electricity generation have several advantages over conventional generation technologies. Reduction of greenhouse gases (GHG) that contribute to global climate change and local air quality is one of the major advantages of RES utilization. Additionally, they reduce the risk of fossil-fuel price fluctuations, spread the energy mixture, and decrease the electricity sector dependency. These advantages can enhance an island's efforts for sustainable power generation.

Greece's national target, according to the EU Directive on Renewables, of 18% of renewables in the final energy consumption in 2020 has been exceeded by almost 4 pp (21,7% in 2020), while the share of renewable electricity was set at 40% (36% achieved in 2020) [33]. Under its National Energy Climate Plan (NECP), the country targets a 35% share of renewables in final energy consumption in 2030, including 60% for electricity, 40% for heating and cooling, and 14% for transport. In the NECP, a target of 2 GW of offshore wind is set for 2030 [33], transforming the islands' areas to the mean for its achievement.

According to the literature, [34], [35] isolated or weak connected power systems are considered all the small and medium-size power systems where no interconnection exists with conterminous and/or continental systems. These power systems face increased problems related to their operation and control, [36], [37]. In most of these systems, dynamic performance is a major concern, since mismatches in generation and load and/or unstable system frequency control might lead to system failures, easier than in interconnected systems.

Renewable Energy Sources and especially wind power exploitation appear particularly attractive. However, the integration of a substantial amount of wind power in isolated systems needs careful consideration, to maintain a high degree of reliability and security of the system operation, [38], [39]. The main problems identified concern operational scheduling (mainly unit commitment) due to high production forecasting uncertainties, as well as steady-state and dynamic operating problems. These problems may considerably limit the amount of wind generation that can be connected to the island's systems, increasing the complexity of their operation. Thus, next to the more common angle and voltage stability concerns, frequency stability must be ensured. This depends on the ability of the system to restore balance between generation and load following a severe system upset with minimum loss of load.

In this study, the recently interconnected power system of Crete Island has been selected as a representative model for long-term energy planning estimation in case of a significant high share in power and energy balance from renewable energy sources. Crete possesses ample wind and solar resources having wind parks and photovoltaic plants with total nominal power of 210 and 120 MW, respectively, and a small hydro power plant with 0.6 kW nominal power. Technically more than 1.2 GW could be harnessed to produce electricity at a reasonable cost if control and management restrictions are excluded. The dispersion of RES installations and the variability of electricity production must be successfully managed by the electricity grid. Generally, the dispersed generation changes distribution networks from passive networks, with power flows from higher to lower voltage levels, into active networks with multi-directional power flows, [40]. Furthermore, transmission and distribution infrastructures require specific economic regulations, [41].

This work investigates the feasibility of further utilization of RES till 2030, in Crete. Real operational data of the examined power system is used as a baseline for the assessment of generation capacity expansion and the optimal energy balance till 2030, taking into consideration previous studies.

2.1 Case Study

Crete is the largest Greek island and one of the largest in the Mediterranean Sea. Its population is currently more than 615,000 inhabitants and it exceeds 2.3 million during the summer. There has been a stable annual electricity demand of approximately 3TWh during the last twelve years, as shown in Figure 1.

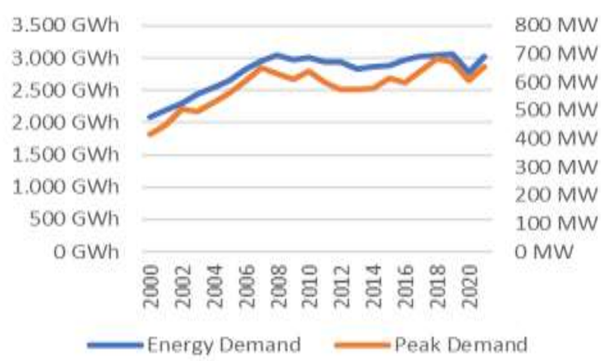


Fig. 1: Evaluation of Annual Load

Additionally, comparing the mean hourly load demand variation all year round, there is a considerable electricity generation diversification between months and seasons, as shown in Figure 2.

However, even during the low consumption periods, the minimum load demand is greater than the current system technical minimum (approximately 120 MW). Island's electricity generation system is based mainly on three (3) oil-fired thermal power units, located as it is shown in Figure 3. The nominal capacity of the local power plants is 742 MW in total, although the actual power is considered to be 721 MW for winter and 674 MW for summer operations, [42].

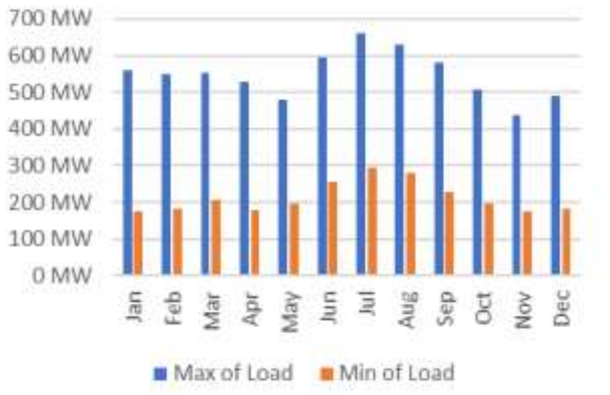


Fig. 2: Monthly Variation of Load (2021)

Fig. 3: Examined Power System

The annual peak load demand occurs on a summer day and within July in this case. Furthermore, the overnight loads can be assumed to be approximately equal to 25% of the corresponding daily peak loads. More precisely, Figure 4 depicts the minimum and the maximum of the daily load demand for one year.

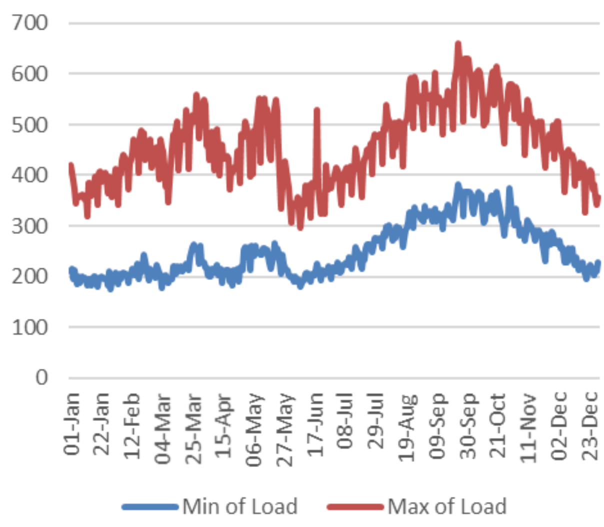


Fig. 4: Daily variation range

The steam and diesel units mainly supply the base-load demand. The Gas turbines normally supply the daily peak load or the load that cannot be supplied by the other units in outage conditions. These units have a high running cost that significantly increases the average cost of the electricity being supplied. The annual duration curve is composed of each generation unit share and is presented in the following Figure 5, where “Conv” represents the total production from all the conventional power units of the island, “RES” the local renewables, and “Link” the AC interconnection with the mainland of Greece.

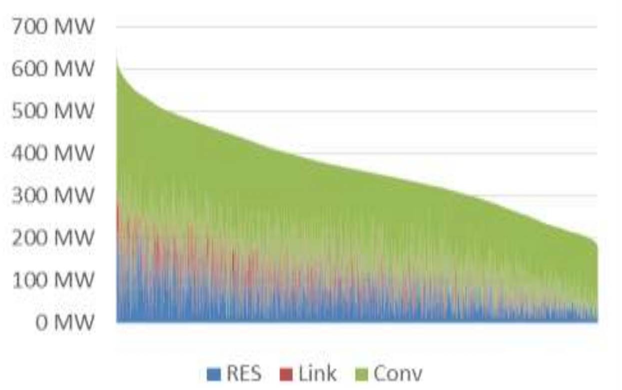


Fig. 5: Crete’s annual load duration curve (2021).

Currently, there are 30 Wind Parks (WPs) installed with a nominal power of 210MW in appropriate regions of the island. These WPs are connected to the grid through MV/HV substations of 20kV/150kV and they are located all over the island as shown in Figure 6.

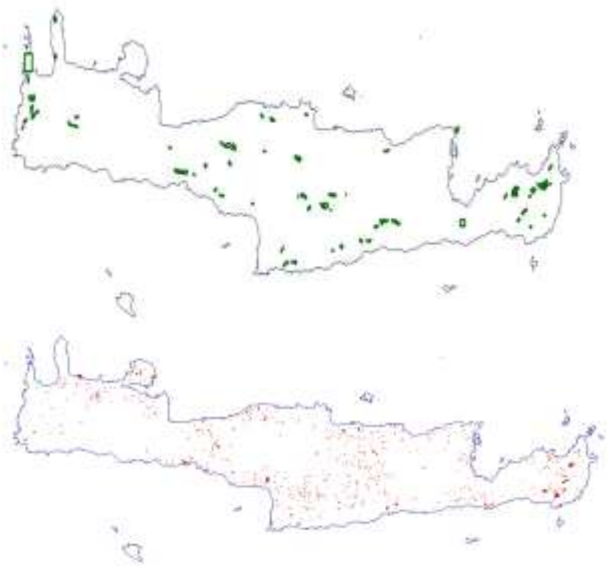


Fig. 6: Geographical allocation of WPs (Green) and PVs (Red) [source: geo.rae.gr]

Elaborating and analyzing all the official (provided by local TSO) recorded data of the load demand and the corresponding RES production of the year 2021, a few interesting figures emerged. In Figure 7 the RES production as a share of the overall generation on a monthly basis is presented. The maximum energy share of RES in a month was 33%, which is considered a significantly high share. In 2021 the RES penetration was varying between 19% and 33% of the total power supply.

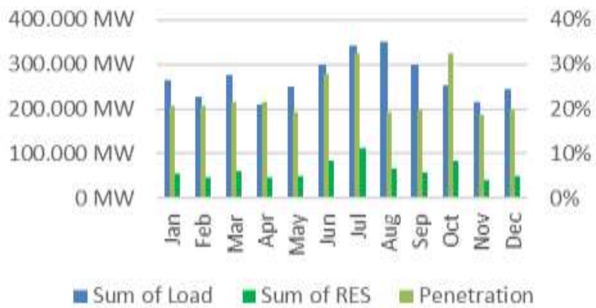


Fig. 7: Load and RES penetration per month

Furthermore, the day (7/8/2021) with the highest share of RES on a daily base is depicted in Figure 8 where the RES power production share reached almost 70%. More precisely, the energy supplied by RES on that day was equal to 3,640 MWh, while the RES penetration varied between 36% and 69% of the total power supply without any significant operation difficulty. Consequently, these are considered significant RES penetration values, especially for an island system such as Crete's network. In the next Figure 9, the hourly average values in the daily base of the wind power and the corresponding penetration of the year 2021 are presented.

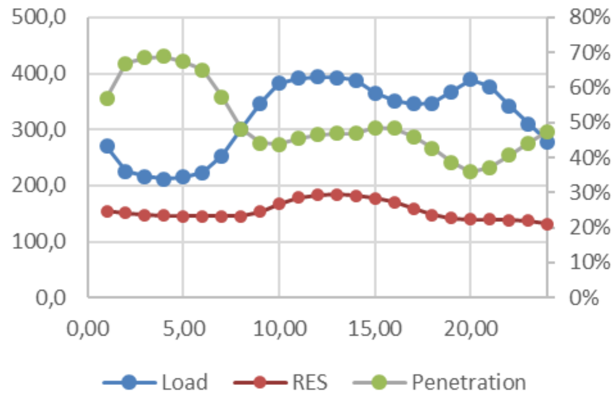


Fig. 8: Highest recording share of RES in the examined island power system

In Figure 9, the annual energy balance of 2021 is depicted. The larger share remains on local oil-fired power plants with a significant share of imports through the new interconnection equal to 12.8%. However, a substantial energy share of more than 33% belongs to the already installed RES on the island. Therefore, according to the current condition of RES and their operation for the year 2021, Crete deals even now with a significant dispersed generation and considerably high penetration of RES. This could be a fine baseline case for extensive new WPs and PV installations, and an even higher RES share till 2030, taking into consideration the prospects and the potential opportunities.

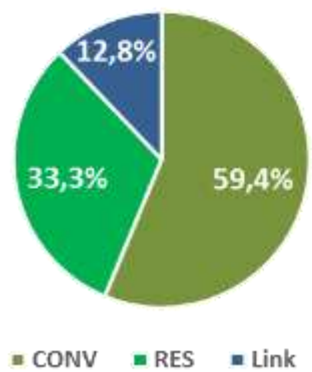


Fig. 9: Energy Balance of 2021

2.2 Future Prospects

The annual electricity consumption in Crete for 2021 was 3.07 TWh, which can be considered as a representative year of load demand, considering the Covid pandemic. During previous years the annual increase in electricity consumption was significant, varying between 4% and 6%. In this study, two cases of the annual electricity demand evolution up to the year 2030 have been considered, as they are depicted in Figure 10 and Figure 11, considering a confidence interval equals to 95%. The second and most moderate scenario of load demand augment, considering both the slight population growth and the energy saving that should be achieved by 2030. Regarding the specific forecast, which is based on the Greek National Energy and Climate Plan (NECP), the annual energy needs of 2030 will vary from an average value of 3.37TWh to a maximum of 4.45TWh.

In addition to the previously mentioned RES power that is already installed, there are current plans for an extra 48 MW new WPs. This fact will lead shortly to even higher wind power up to 258MW. Furthermore, 140MW of new small-scale PVs are planned to be installed by 2030, adding up a total of 250MW of PVs.

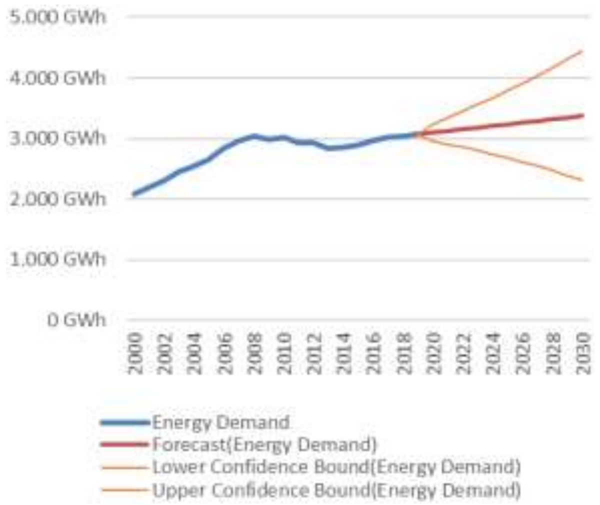


Fig. 10: Annual Energy demand evolution estimations

Thereupon, in this study three (3) main scenarios groups of sustainable expansion were investigated concerning the maximization of WPs and PVs capacity till 2030, as presented in Table 2. The study has considered hourly-based operation and the corresponding technical limitations of the power system. In the first two (2) scenarios, the local RES is increasing, finding the best mix between PVs and WPs, till the point where their rejection, due to power system constraints reaches 5% of their total annual production. This approach tends to go safely beyond the targets of Greek NECP for the island. The next scenarios assume a quite extensive installation of electricity storage systems (ESS) up to 600MW and 4.8GWh of energy capacity [43]. This approach is considered to support an even higher expansion of RES on the island by 2030.

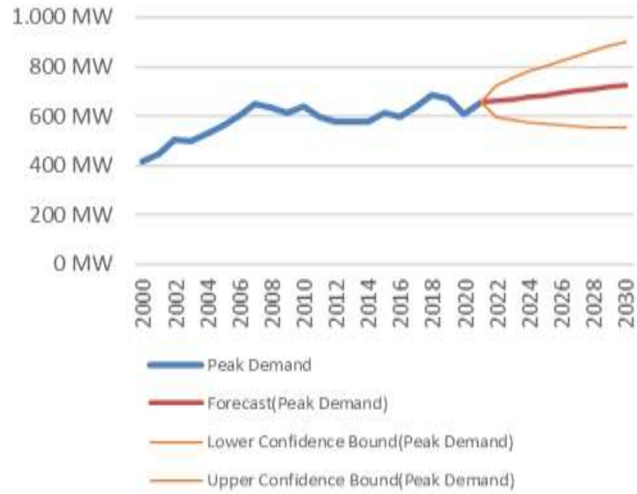


Fig. 11: Peak Load demand evolution estimations

Table 2. Scenarios of RES power expansion in 2030

Scenario	Peak Load	Energy 2030	Description
A1	726 MW	3.37 TWh	Max WPs & PVs
A2	901 MW	4.45 TWh	Max of WPs & PVs
B1	726 MW	3.37 TWh	Max of WPs & PVs with ESS
B2	901 MW	4.45 TWh	Max of WPs & PVs with ESS
C1	726 MW	3.37 TWh	Max of WPs & PVs with ESS and DC Link
C2	901 MW	4.45 TWh	Max of WPs & PVs with ESS and DC Link

2.3 Methodology

This paper presents a program with an algorithm that is developed to optimally expand the local RES potential of an area (an interconnected island in the examined case) without risking the normal operation of the specific power system. Additionally, the impacts of different scenarios of generation expansion planning have been taken under consideration in the Cretan Power System operation. The previously mentioned scenarios focus on the future energy demand, in particular the energy demand by 2030, and the corresponding energy balances.

Different energy balances have been calculated by taking into account both the current way of generation expansion, the possible use of electricity storage systems, and the future implementation of a new larger interconnection. All these schemes have been investigated and their impact on CO_2 emission mitigation and RES production rejection have been estimated. The constructed model incorporates a range of energy demand on hourly base (8760 values of each parameter), taking into consideration the transmission limitations. In conclusion, four (4) representative approaches have been carried out to expand RES generation till 2030, where the main objective is the minimization of local oil-fired electricity production, whereas the main constraint is the RES rejections to be less than 5%:

a. In the first two scenarios of medium (A1) and high (A2) load demand increment till 2030, the energy penetration of RES technologies will be increased till the total RES rejection on the island is less than 5%, without BESS installation.
b. In the second two scenarios of medium (B1) and high (B2) load demand increment till 2030, the energy penetration of RES technologies will be increased till the total RES rejection on the island is less than 5%, but in these cases, BESS installation is considered.
c. In the second two scenarios of medium (C1) and high (C2) load demand increment till 2030, the energy penetration of RES technologies will be increased till the total RES rejection on the island is less than 5%, but in these cases, both BESS installation and new DC link are considered.

2.4 Carbon Intensity of Electricity

Carbon intensity of electricity measures the amount of CO_2 that is produced per unit of electricity. It is measured as the grams of CO_2 produced per kilowatt-hour (kWh). Electricity nonetheless comes from various sources such as fossil fuels (coal, oil, and gas summed together), nuclear power, or RES.

The CO_2 emissions in this analysis are determined by the product of Energy Consumption (E) with the Emission Factor (EF) as shown in the following equation, [44]:

$$CO_2\text{Emissions} = E \times EF$$

Therefore each region's carbon intensity of electricity differs based on its Energy Balance and thus this study takes under consideration the transformation of energy into CO_2 emissions the depicted annual energy balance of Crete as presented in Figure 9. As countries or researchers do not compile their Emission Factors (EFs) in the same way, one should use the EF which can represent the average emissions rate for a specified activity occurring at a national or regional scale and thereby may represent a range of specific technologies and practices (e.g., national steel production). Taking that under consideration in this study Greece's yearly CO_2 Emission Factor was used for the analysis of the data presented in Figure 19.

2.5 Algorithm Flow Charts

In the following Table 3, the used abbreviations are explained. This methodology uses an algorithm that is developed to simulate and estimate the impacts of different future generation expansion scenarios in Cretan Power System operation.

Table 3. Abbreviations Description

LOAD	Load Demand per hour
PV	Photovoltaics production per hour
WT	Wind park production per hour
RES	The total renewables production (PV+WP)
LINK	Energy flow through the island interconnection
SURPLUS	Renewable energy surplus (RES - LOAD)
LINKCAP	Interconnection power flow capacity
CONV	Local oil-fired power plant
ESS	Energy flow of the island energy storage systems
ESSCAP	ESS capacity
REJECTION	RES production rejection by systems' technical limitation

In Figure 12, the flowchart of the proposed algorithm that uses the parameters, which are described in Table 3, is presented.

The second to last step is to calculate the Link with the continental grid. Taking for granted that the Link limit is 200 MVA and already know the RES-NET from the previous equation, it is possible to find the Link (diagram 1.5).

The last step is to find how much energy Thermal (diagram 1.6) has to be produced from the power plants to cover the rest of the load that can't be covered by RES, batteries, and Link together.

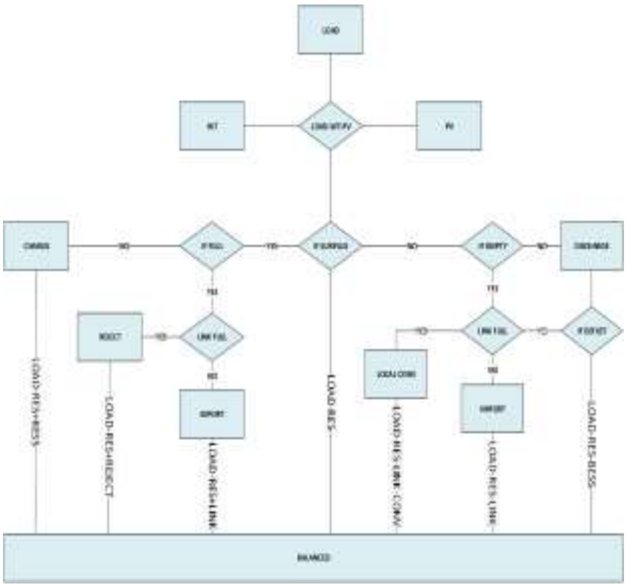


Fig. 12: Proposed algorithm calculations flowchart

In Figure 13 a screenshot of the developed program is presented. The dashboard of the program shows the results of each scenario, such as generation sources installed capacity, annual energy balance and relevant energy shares, energy exchanges through interconnections, and detailed information on local energy storage systems.

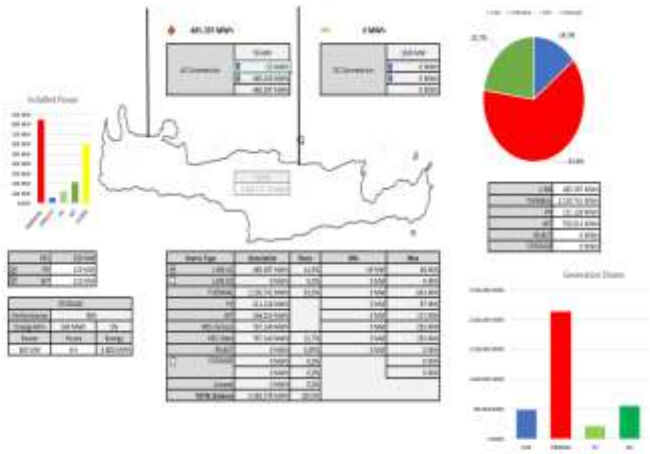


Fig. 13: Developed program interface

The Generalized Reduced Gradient (GRG) method has been used in this study to find the optimal solution for the proposed approach. The GRG method is an extension of the reduced gradient method to accommodate nonlinear inequality constraints. In this method, a search direction is found such that for any small move, the current active constraints remain precisely active. If some active constraints are not precisely satisfied because of the nonlinearity of the constraint functions, the Newton–Raphson method is used to return to the constraint boundary. Thus, the GRG method can be considered somewhat similar to the gradient projection method, [45].

3 Results

In Figure 14, the results of the baseline state (year 2020), where the island was non-interconnected, are presented. That year, all its energy needs were covered by local power plants and renewables (PVs and WPs), which were 120 MW of PVs and 210 MW of WTs on the island.

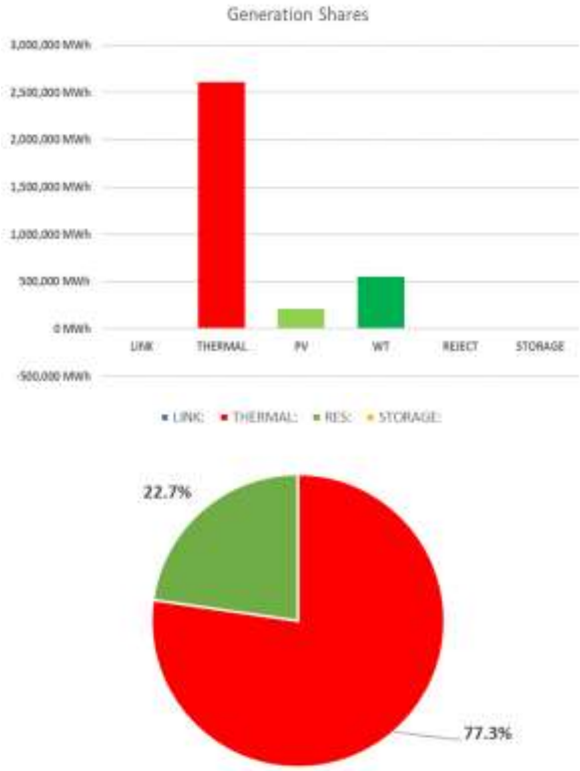


Fig. 14: Operation Analysis of the Power System in 2020

In Figure 15, the results of the current state (year 2023) of the power system with a 200MVA interconnection, are presented. In particular, 22.7% of the annual load demand had been covered by RES, 14.3% by the interconnection, and 63.0% by local oil-fired power plants. If we compare these numbers with those of 2020 (Figure 14), we observe that the production of power plants was reduced by 14.3%, because Crete's system did not any interconnection with the mainland of Greece. This translates into a reduction of 3.86 million tons of CO_2 assuming that 1MWh emits 0.27tones of CO_2 equivalent.

In the first group of scenarios, as depicted in Figure 16, RES installed power is maximized to the point that annual RES production rejections/curtailments are maintained at lower than 5%. More precisely, the algorithm calculated that the maximum new PVs installed power can be between 248MW and 326MW without any serious curtailments in their annual production. In the same manner, the maximum new WP installed power can be between 633MW and 831MW. In that case, the local power plant production share is reduced by 52.4%, whereas the RES share increases up to 81%.

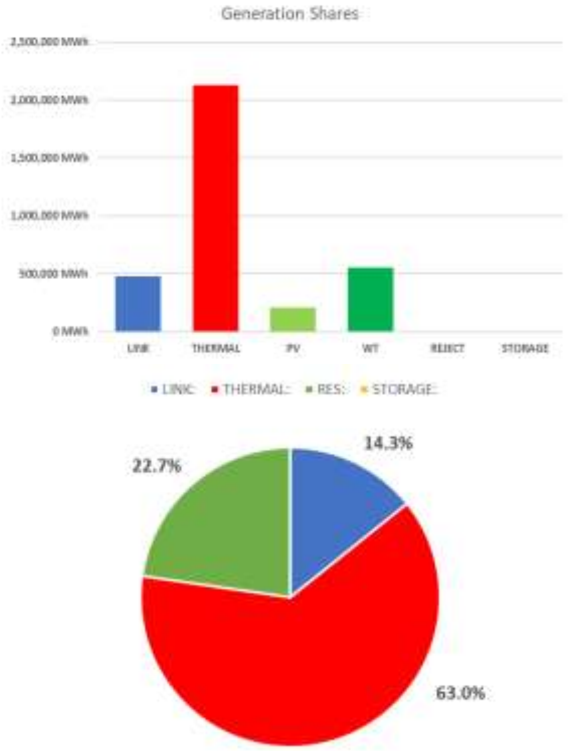


Fig. 15: Operation Analysis of the Power System in 2023

In the second group of scenarios, the utilization of electricity storage systems is considered in the examined energy balance. In this way, it is possible to manage even higher values of RES power without rejecting large amounts of energy. The goal of RES energy rejections of less than 5% remains in these scenarios, too. Following the results of our previously conducted research, the planned capacity for future energy storage systems in the specific island is considered to be 4.8GWh at 600MW charge and discharge rate, [43].

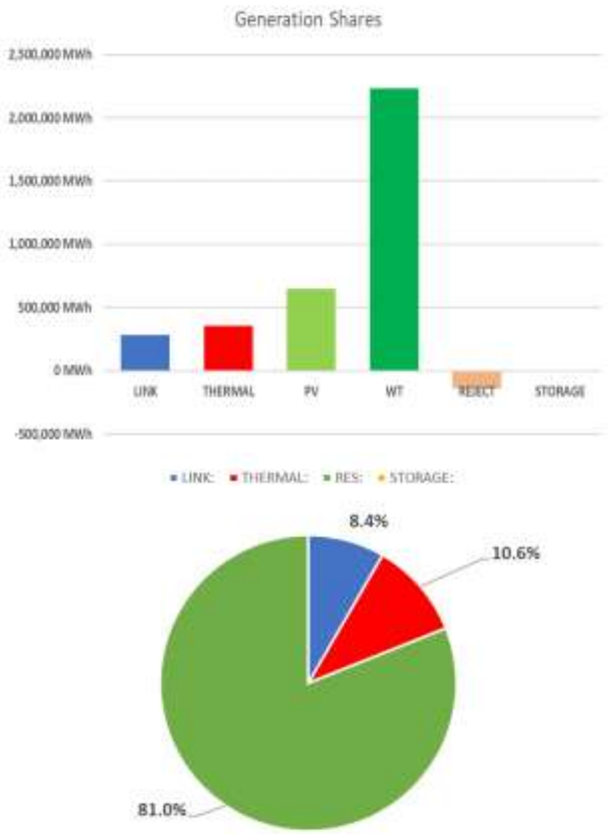


Fig. 16: Operation Analysis of Scenario A1 with further expansion of RES in 2030

The results, as depicted in Figure 17, show an even higher RES penetration up to 90% in the annual energy balance and an even lower share of oil-fired power plants equal to 4.5%. It is worth mentioning that BESS systems have a significant share of 4.4% in the energy balance, which is the main factor of the high-RES share in these scenarios. Regarding the new RES power capacities, in these cases, they vary between 339MW and 405MW for new PVs, and between 722MW and 1058MW for new WTs.

In the third group of scenarios, besides storage, a new interconnection is constructed and it will be in operation by 2025. In that way, the system can have the maximum possible RES capacity, which can supply all the needs of the island, in collaboration with the local BESS. The goal is once again that the annual RES energy rejection should be less than 5%.

More precisely, the algorithm calculated that the maximum new PVs installed power can be between 538MW and 591MW without any serious curtailments in their annual production, whereas the maximum new WPs installed power can be between 2125MW and 2562MW. In that case, as shown in Figure 18, the local power plant production share is zero, whereas the RES share increases up to 96% with the BESS contribution to be 3.8%.

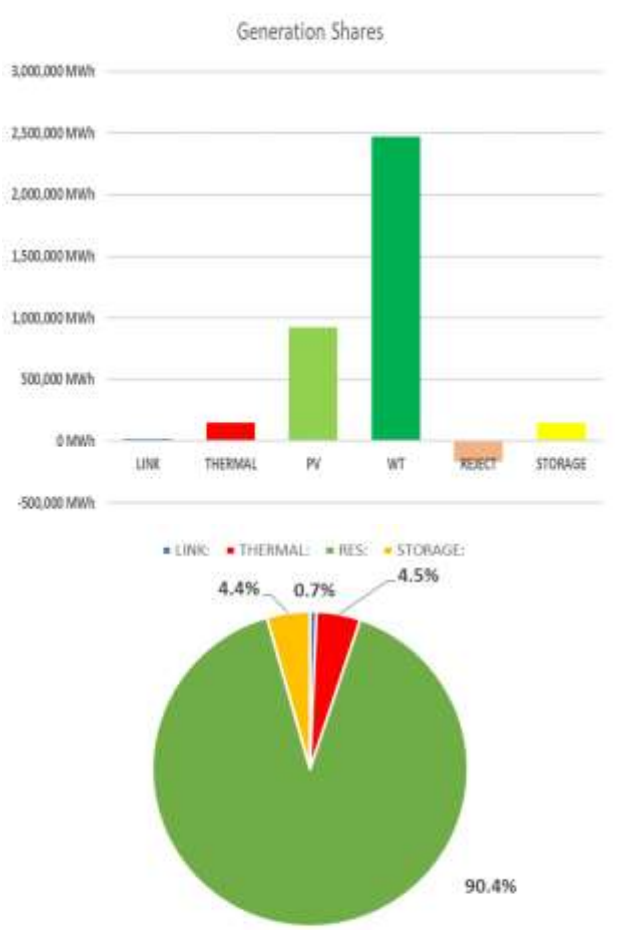


Fig. 17: Further expansion of RES using ESS of 600MW/4.8GWh by 2030

In conclusion, the extracted results of all the scenarios are presented in Table 4, where the forecasted energy needs and the relevant power peaks are depicted, in parallel with the corresponding new PVs and WTs that can be installed without being rejected more than 5% in the annual base.

Table 4. Results of all the examined scenarios

Scenario	Peak Load	Energy 2030	New PVs	New WPs	Local Thermal
A1	726MW	3.37TWh	248MW	633MW	357.4GWh
A2	901MW	4.45TWh	326MW	831MW	668.0GWh
B1	726MW	3.37TWh	339MW	722MW	152.0GWh
B2	901MW	4.44TWh	405MW	1058MW	392.6GWh
C1	726MW	3.37GWh	538MW	2125MW	-
C2	901MW	4.44GWh	591MW	2562MW	-

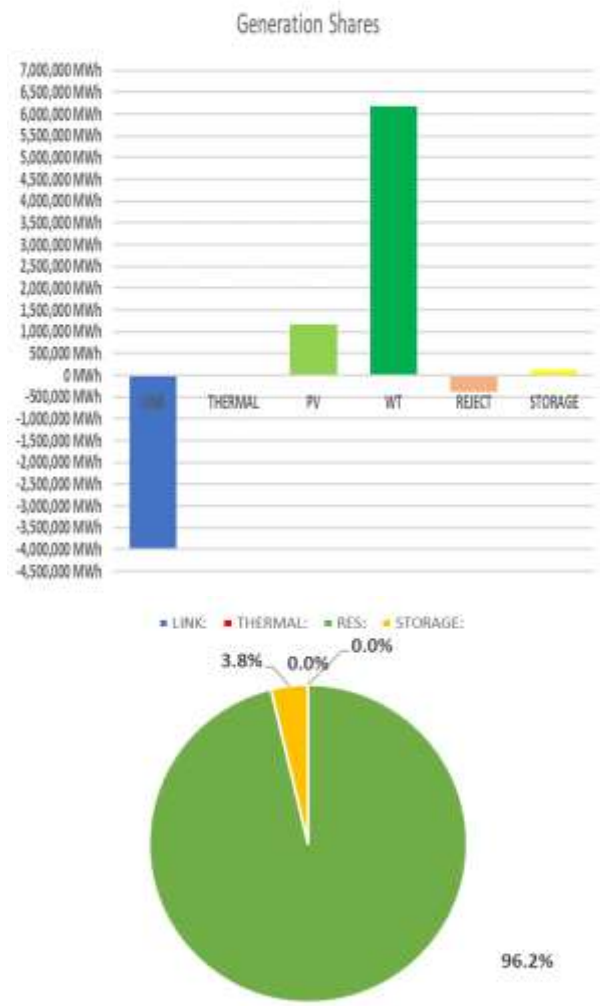
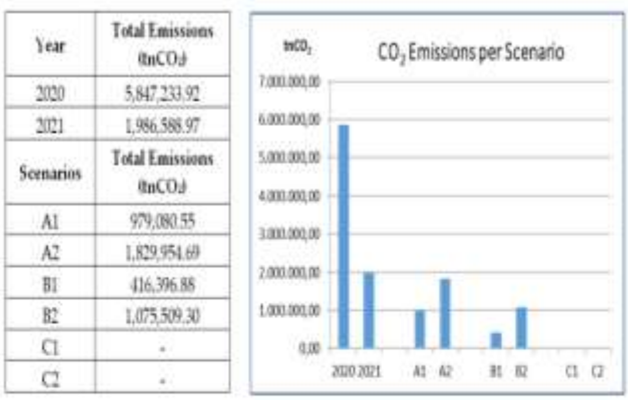


Fig. 18: Further expansion of RES using both ESS and new DC interconnection by 2030

Following the previously presented results of new PVs and WTs that can securely be installed in the examined power system, an estimation of the resulting CO_2 emission reductions is presented in Figure 19 below, taking into account Greece's EF factors per 1 kWh thermal energy production.



Year	Total Emissions (tnCO$_2$)
2020	5,847,233.92
2021	1,986,588.97
Scenarios	**Total Emissions (tnCO$_2$)**
A1	979,080.55
A2	1,829,954.69
B1	416,396.88
B2	1,075,509.30
C1	-
C2	-

Fig. 19: Total CO_2 Emissions per year and Scenario estimation

Figure 19 outlines the significant mitigation of CO_2 emissions not only between the year 2020, when Crete was not connected with the main grid, and 2021 when the first Link was achieved, but also within Table's 4 scenarios. From 2020 to 2021 Crete achieved a reduction of 98.2 5% just by connecting with the national grid. This reduction is also noticeable even between the A2 scenario and Crete's current energy production (8% from 2021). Nonetheless one cannot ignore CO_2 mitigation even between the scenarios, as a reduction of 50.7% for A1; 79% for B1, and 45.86% for B2 is estimated to be achieved.

4 Conclusions

This paper investigates RES's contribution in the energy balance and CO_2 eq. emissions of Crete's grid. A methodology has been introduced that optimizes the penetration level, maximizing local RES production, increasing the self-sufficiency of the island, and keep RES energy rejection/curtailments below 5%. Although there is the needed capacity of RES that could cover the corresponding demand, the current power system structure, and operation emerge limitations, which hold back their further exploitation. The introduction of energy storage systems, such as pump storage and batteries can help the further exploitation of the needed RES by balancing the current load demand and the intermittent power flow of photovoltaics and wind turbines. This paper analyses a recently interconnected island power system operation, as a representative case study, and demonstrates benefits, such as CO_2 emissions reduction, and obstacles emerged by ultra-high penetration of RES. This ultra-high share of RES is technically feasible, through strong interconnections and BESS, resulting in significant CO_2 mitigation.

Considering our national multi-level efforts for the achievement of the new National Energy Planning goals, Greece's new national production structure should be Green (based on sustainability), Smart (using artificial intelligence and other digital achievements and applications), Fair (in social and spatial level), Inclusive (so as not to leave out the weak) and with National Added Value (through the creation of adequate permanent jobs).

The scenarios' results confirmed that the high RES technologies penetration significantly affects the mitigation of CO_2 emissions. Thus the combination of grid enhancement along with the utilization of RES technologies would not only reduce greenhouse gas emissions [5], mitigating climate change, but it would also benefit Crete on social and economic levels, as new job opportunities would appear, [46] and energy poverty would be also moderated, [47], [48].

Based on the results of this research, several paths of future work can be outlined for exogenous factors such as pandemics (e.g. COVID-19), wars (e.g. Ukraine war) and natural disasters (e.g. earthquakes) to be investigated in the energy emissions model combined with the application of energy forecasting models that use actionable parameters, [48]. Including such variables could reveal an energy dependency which could lead to the modification of energy policy of EU countries towards energy self-sufficiency, [5].

In conclusion, a sustainable power generation expansion planning, which combines grid enhancement, advanced operation control, substantial PVs, and WPs exploitation in collaboration with adequate electricity storage systems, overcoming current technical and operational limitations, could lead to a realistic environmentally neutral power system by the end of 2030, attaining much earlier the EU green deal goals in local scale, along with providing solutions in problems such as the lack of fresh water and energy independence in remote islands [50]. In the future, further research of the interaction from the introduction of this concept to Local Regional Authorities could further optimize RES penetration level, [51] and CO_2 emissions reduction, [52].

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