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Assessing the Status of Electricity Generation in the Non-Interconnected Islands of the Aegean Sea Region

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Abstract

Assessment of the electricity generation status for Non-Interconnected Islands (NIIs) of the Aegean Sea region, excluding the electricity systems of Crete and Rhodes, is undertaken in the current study. The authors focus on the long-term analysis of thermal power generation characteristics and also on the challenges so far limiting the contribution of Renewable Energy Sources (RES) in covering the electricity needs of the specific area. According to the present analysis, due to the existing technical limitations, the annual RES shares in the electricity balance of NIIs of the Aegean Sea have since 2010 stagnated in the range of 15% to 18%. Moreover, the performance of thermal power stations for all 30 NII systems is evaluated on the basis of their utilization factor, associated fuel consumption and electricity production costs. The vast majority of these stations is characterized by low capacity factors in combination with high specific fuel consumption and high operational expenses that in the case of smaller scale island regions could even exceed 600€/MWh. At the same time, the authors discuss on the alternatives and encourage further investigation of novel, intelligent energy solutions, such as the smart microgrid and battery-based hybrid power station that are currently developed on the island of Tilos under the implementation of the TILOS Horizon 2020 program.

Keywords: Renewable Energy Sources; Island Systems; Aegean Archipelagos; Autonomous Power Stations; Energy Storage; TILOS project

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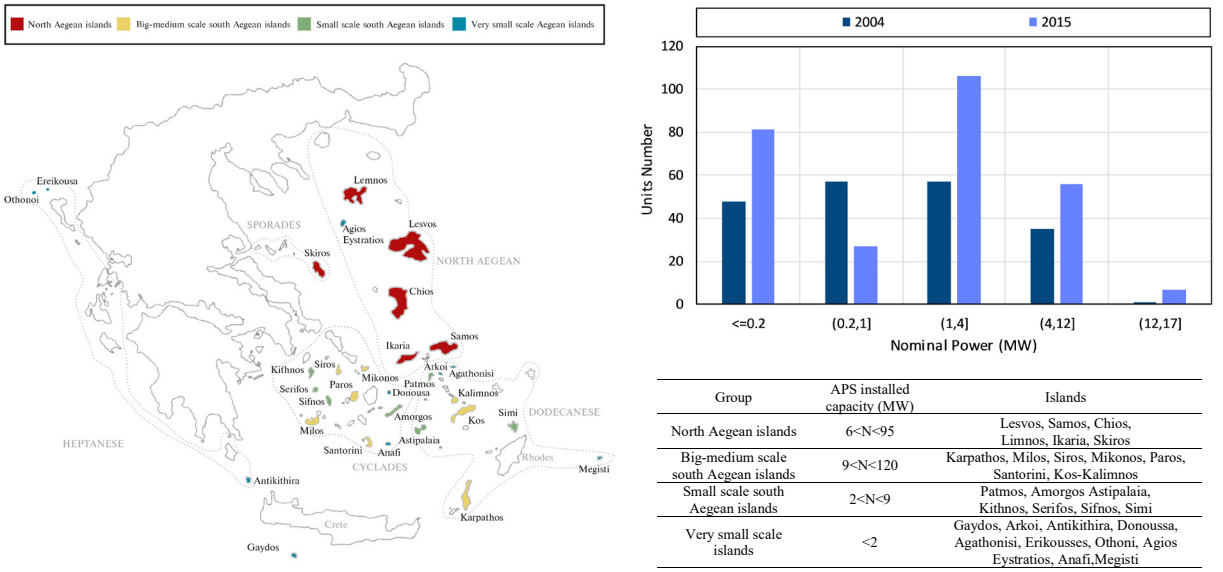
1. Introduction

The majority of islands globally present considerable energy supply problems and increased oil participation in their energy mixture [1,2]. Supply security links to both the dependence on oil imports and the fact that most of these islands are not interconnected to a stable, mainland electricity grid, with the most remote of them facing even greater challenges in the event of a grid failure or severe damage of the local power stations [3]. Increasing energy security to this end would require not only a decrease of energy dependence on imported fuels [4], but also the establishment of a diversified energy mix [5], allowing for the contribution of high shares of Renewable Energy Sources (RES) power generation. On the other hand, achieving high RES shares normally comes with a price, meaning that the greater the contribution of RES in such isolated grids of reduced capacity, the greater the risk that has to be hedged by the local operator, either through the employment of sufficient reserves [6] or through the imposition of RES curtailments [7,8]. To address this issue, local operators apply certain limitations associated with the dynamic penetration of RES and the non-violation of technical constraints (technical minima) for the existing thermal power units, which normally results to a maximum contribution of RES in terms of covering the local energy consumption, in the order of 15-20% on an annual basis. Meanwhile, several of these isolated island areas appreciate excellent RES potential conditions [9,10] that encourage further investigation on the means required to maximize RES integration. In this context, and owing also to the growth encountered in the energy storage industry and market nowadays [11,12], arguments have become stronger with regards to the view that integrated, smart energy solutions, combining RES, energy storage and other elements such as Demand Side Management (DSM), advanced energy management, etc., could replace oil-based power generation in a cost-efficient manner [13-15]. This is more evident for the most remote and smaller-scale island areas, where due to the remoteness factor and due to economies of scale, oil-based power generation suggests remarkably high electricity production costs that could even exceed 600€/MWh. Acknowledging the above, the current study aims to provide a detailed assessment of the electricity generation status in the Non-Interconnected Islands (NIIs) of the Greek Aegean Sea, recording the evolution of main parameters and features concerning the local electricity sector during the last 10-15 years. The study is novel in the sense of recording long-term data and offering also an update of previous studies in the field [4] while capturing a broad island region with islands of different scale and characteristics.

2. Thermal Power Generation in NIIs of the Aegean Sea

To facilitate the investigation of the electricity generation status in Aegean Sea NIIs, islands examined are categorized by geographical area and size, the latter determined in accordance with the capacity of the local thermal power stations. It is noted at this point that the NIIs' electricity requirements are to date mainly satisfied by autonomous power stations (APS) comprising of internal combustion engines. More precisely, the electricity needs of the islands are mainly covered on the basis of 30 APSs [16] with a total real power of ~700MW (excluding the systems of Crete and Rhodes while including islands of the Cyclades' complex that were only recently interconnected to the Greek mainland), featuring permanent and also portable units of a wide capacity range. To this end, NIIs of the Aegean Sea are divided in four major groups (see also Fig. 1) corresponding to North Aegean Sea Islands, Big-medium South Aegean Islands, Small South Aegean Islands and Very Small Islands across the entire Aegean Sea, in relation also to the different installed capacity of the local APSs and thermal units employed (see also right part of Fig. 1). Installed capacity of local APSs, when compared to the peak demand of island systems, can also be seen as a measure of supply security. Such a comparison is obtained from the four graphs of Fig. 2, where apart from the comparison attempted with the appearing peak load demand, the installed capacity of local APSs is further analyzed to permanent, portable and new one, revealing the need of big-medium and touristic South Aegean islands for additional thermal power capacity during the summer period. On the other hand, the increase met in the local electricity consumption of NIIs during the summer season implies lower utilization of thermal units, especially if the latter are oversized in comparison to the actual island electricity needs, which seems to be the case for the small and very small Aegean islands. Low utilization of the existing APSs, which is more pronounced in the case of smaller scale islands is better reflected in Fig. 3a, where the respective annual capacity factor is provided for years 2014-2016 and also for year 2004 (dropping even below 10%), aiming to also designate the impact -if any- of the economic crisis on electricity consumption and thus on the capacity factor values of the local APSs.



Group	APS installed capacity (MW)	Islands
North Aegean islands	6<N<95	Lesvos, Samos, Chios, Limnos, Ikaria, Skiros
Big-medium scale south Aegean islands	9<N<120	Karpathos, Milos, Siros, Mikonos, Paros, Santorini, Kos-Kalimnos
Small scale south Aegean islands	2<N<9	Patmos, Amorgos Astipalaia, Kithnos, Serifos, Sifnos, Simi
Very small scale islands	<2	Gaydos, Arkoi, Antikithira, Donoussa, Agathonisi, Erikousses, Othoni, Agios Eystratios, Anafi,Megisti

Fig. 1. Classification of NIIs per geographical area and APS installed capacity and nominal power of thermal units employed

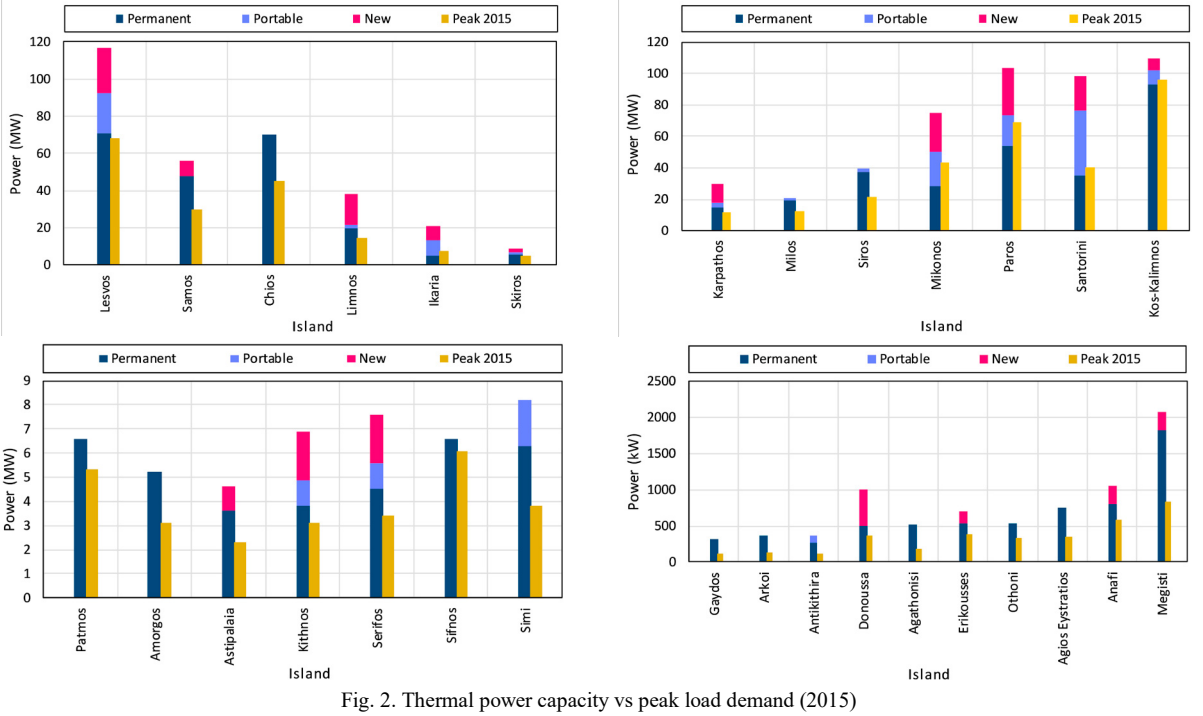


Fig. 2. Thermal power capacity vs peak load demand (2015)

The latter argument can only be partly confirmed from Fig. 3b, where the long-term, total fuel consumption of NIIs' APSs is depicted, showing a constant increase from 1990 onwards and only a slight reduction during the period 2009-2013, i.e. when an increase of the cheaper heavy-oil shares has been noted again, in the expense of diesel oil. It is also mentioned at this point that during the same period, RES shares did not present any significant increase (see also section 3) and thus the decrease met in fuel consumption should be attributed to a reduction of the overall electricity consumption. At the same time, low capacity factors are combined with high specific fuel consumption (SFC) as well, in the order of 250gr/kWh, that in turn leads to quite high electricity production costs for the majority

of the local APSs. This is better illustrated in Fig. 4a, where the electricity production costs of the different NIIs is provided, found to even exceed 600€/MWh for certain small scale island cases. High values of SFC together with increased maintenance needs and APS assets' amortization have led to a long-term increase of the total production cost, exceeding during the recent years even 300M€ on an annual basis (excluding the electricity systems of Crete and Rhodes) and being directly dependent on the price volatility of imported oil quantities (Fig. 4b). Further breakdown of fuel-only costs, being the most important component determining total costs, is provided in Fig. 5, per NII, demonstrating at the same time the use of diesel-oil for the small and medium scale islands, and the almost exclusive use of heavy-oil for the biggest of island systems.

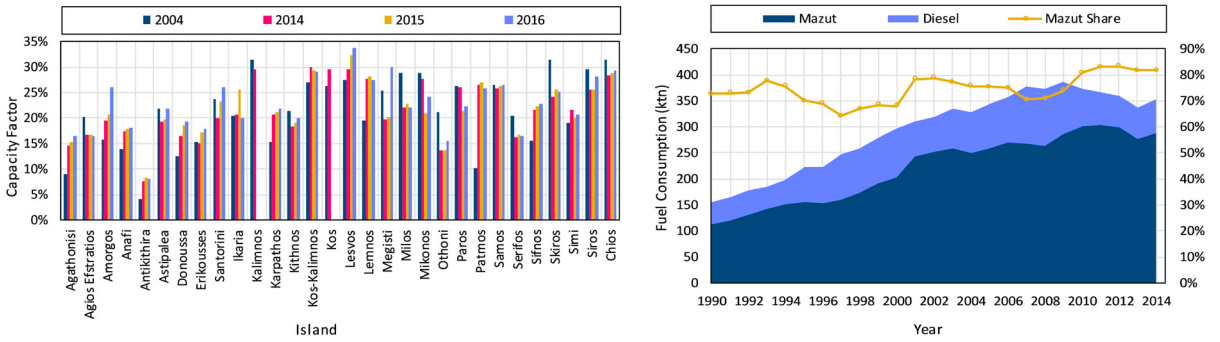


Fig. 3. Annual capacity factor of local APSs (a) and long-term evolution of fuel consumption for NIIs APSs (b)

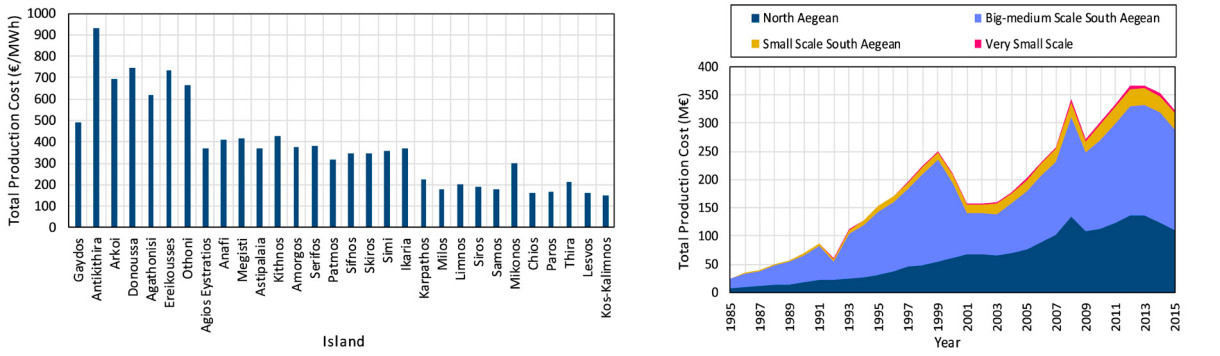


Fig. 4. Electricity production cost of NIIs (2014) (a) and long-term evolution of total costs for NIIs APSs (b)

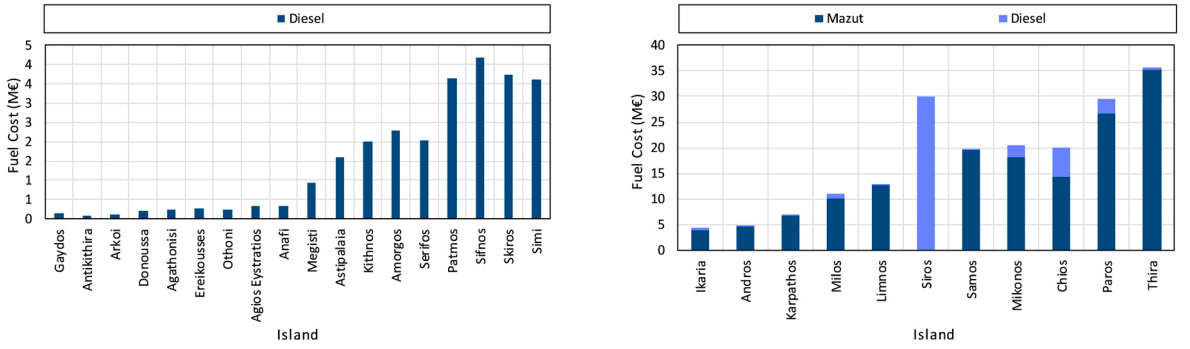


Fig. 5. Annual fuel costs and heavy-oil / diesel-oil balance per NII (2014)

3. RES Power Generation in NIIs of the Aegean Sea

Despite the very high-quality wind potential encountered in many of the NIIs and also the excellent solar potential met across the entire Aegean Sea area, the progress recorded in the field of RES power generation has not

been the one anticipated. According to recent official data [17], wind power has stagnated at ~75MW, including almost 100 wind farms distributed mainly in the biggest and medium scale islands of the Aegean Sea, while PV capacity is in the order of 40MW, again concentrated in the biggest scale islands of the area (see also Fig. 6).

Stagnation met in the installation of new RES plants is also reflected in Fig. 7a, where contribution of RES generation in the coverage of the local electricity consumption is provided for all NIIs, on a monthly basis. As one may obtain from the graph, RES shares appear almost constant, although actually increasing from 15% in 2011 to 18% in 2017. The specific penetration ceiling is the result of local grids' limitations (dynamic penetration limits and thermal units' technical minima constraints) that discourage the installation of new RES plants, owing to the increased curtailments to expect. Increased curtailments for existing wind parks are already a reality in saturated island electricity systems, such as the one of Kos and Kalymnos, where local wind parks of close to 15MWs installed capacity face curtailments that could even reach 30% of the respective annual wind energy yield [18]. As a result, the actual capacity factor of wind installations (Fig. 7b) is challenged by the existing grid and thermal units' limitations, not allowing for the maximum exploitation of the available wind energy resources of the area.

To address the issue of limited RES contribution, pilot projects developing advanced, integrated solutions that employ energy storage and intelligent management aspects (DSM and forecasting), could lead the way. In this context, the innovative TILOS Horizon 2020 project [19] that is implemented on the island of Tilos, belonging to the saturated -in terms of RES installations- Kos and Kalymnos electricity system, demonstrates how community-scale battery storage could be optimally combined with local RES power generation and DSM, delivering in the meantime the first-ever Power Purchase Agreement for a MW-scale battery-based Hybrid Power Station (HPS) in Greece. It is important to mention at this point that according to a recent survey (September 2017) carried out from WWF Greece, the University of West Attica and the University of East Anglia, and capturing ~1000 respondents across 15 Aegean Sea islands, 75% of the islanders are in favor of adopting the Tilos island paradigm instead of the current oil-based power generation energy model.

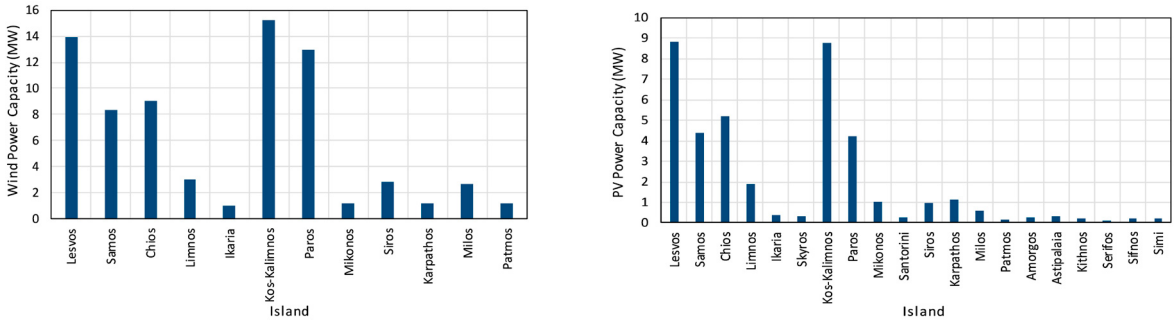


Fig. 6. Installed wind power capacity (a) and PV power capacity (b) in NIIs of the Aegean Sea (end of 2016)

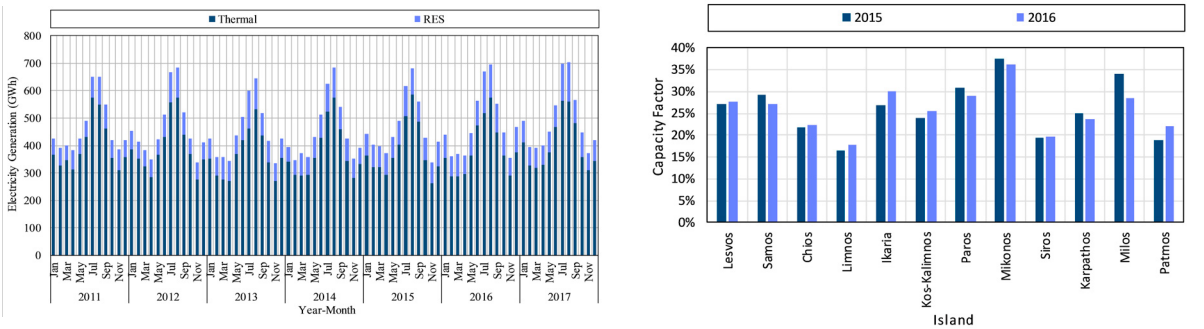


Fig. 7. Long-term evolution of RES and thermal power generation in NIIs (a) and wind parks' capacity factor (b)

Conclusions

The main objective of the current work was the assessment of the electricity generation status in the NIIs of the Aegean Sea, with emphasis on the analysis of thermal power generation characteristics and on the illustration of the slow progress achieved regarding RES contribution over the last decade. According to the data presented, the local electricity generation still relies heavily on conventional power plants characterized by low capacity factors and high specific fuel consumption, which results in electricity production costs that can even exceed 600€/MWh for the smaller scale island regions. To address the existing situation and also ensure increased levels of supply security, the development of smart energy solutions and battery-based HPSs seems to be the main alternative for the smallest and most remote island regions of the Aegean Sea. On the other hand, interconnection plans provide another feasible alternative, mainly for the larger scale islands and complexes located close to the Greek mainland, while for the rest of medium-scale islands, larger scale storage could be employed to support increased shares of RES.

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