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Sustainable island power system – Scenario analysis for Crete under the energy trilemma index☆

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ABSTRACT

Sustainable energy supply is an essential part for economic and social development in every society. Islands as geographical isolated regions have to confront a number of challenges to secure a reliable and clean energy system. Currently, electricity demand on the Greek island of Crete is supplied by oil-fired engines imposed to new emissions restrictions applied from 2020. Thus, a capacity upgrade is necessary and new solutions driven by renewable energy, energy storage and interconnections. This study investigates three scenarios: Business as Usual (BAU); Natural Gas (NG); and the Interconnection of Crete with the National Grid System (Int.) to assess the potential techno-economic and environmental impact of the required transition under the Energy Trilemma Index. A capacity expansion and operation optimisation process has been applied through a high resolution spatio-temporal analysis performed with PLEXOS Integrated Energy Model. It was concluded that no BAU Scenario could facilitate a future plan for the electricity system of Crete or any European island imposed to such constrains. The optimum scenario incorporates interconnectors and energy storage systems that manage to deliver 52% reduction in the total system costs (2020–2040), 79% in electricity generation costs and 48% reduction in GHG emissions by 2040, compared to the BAU.

1. Introduction

More than 100,000 islands across the world (Richardson, n.d.) struggle to secure a reliable energy system with affordable energy prices and low carbon intensity. In particular, non-interconnected islands (NII) characterized by energy isolation, depend mostly on diesel and heavy fuel oil as their primary electricity source resulting in economic and environmental impediments. 'Energy Islands' can be considered beyond the geographical non-interconnected islands, any remote rural and weakly interconnected area which strives for affordable and sustainable energy supply.

According to the report of the United Nations conference on Environment and Development in Rio in 1992, "islands are ecologically fragile and vulnerable" (United Nations, 1992). Two years later, the 'Programme of Action for the Sustainable Development of Small Island Developing States' was established (United Nations, 1994). Although islands usually comprise small regions, possess a significant yet unexploited renewable energy potential making the electricity sector a driver towards decarbonization in the energy transition of islands' economies (Eurelectric, 2012). Examples across the world from the Pacific to the Caribbean Islands and the Mediterranean Sea demonstrate as examples with abundant wind, solar and other natural energy resources. In the European context, several declarations have been recorded from the Canary islands - Palma de Mallorca declaration in 1999 and the Chania declaration in 2001 (Cipriano, 2015) to the latest one, in Malta for Clean Energy in EU islands (European Commission, 2017a). Key catalysts towards the overall improvement on islands have been initiatives such as the Covenant of Mayors, the Pact of Islands, the Smart Islands Initiative and recently the Clean Energy for EU Islands as part of the Clean Energy for All Europeans which addresses challenges related to islands prosperity and sustainability in Europe (European Commission, 2016c).

In that respect, Island System Operators (ISOs), producers and power suppliers on islands aim to transit towards a more robust and sustainable energy system. The European governments have approved that the dominant target of framing the low carbon energy transition problem is replacing old fossil fuel plants with zero carbon technologies. This barrier could be addressed by transforming islands and remote, energy isolated regions into test-beds and apply advanced technologies such as: interconnectors, smart energy systems such as demand response with increased energy efficiency, energy storage and electrification of the transport sector accompanied by target policies and

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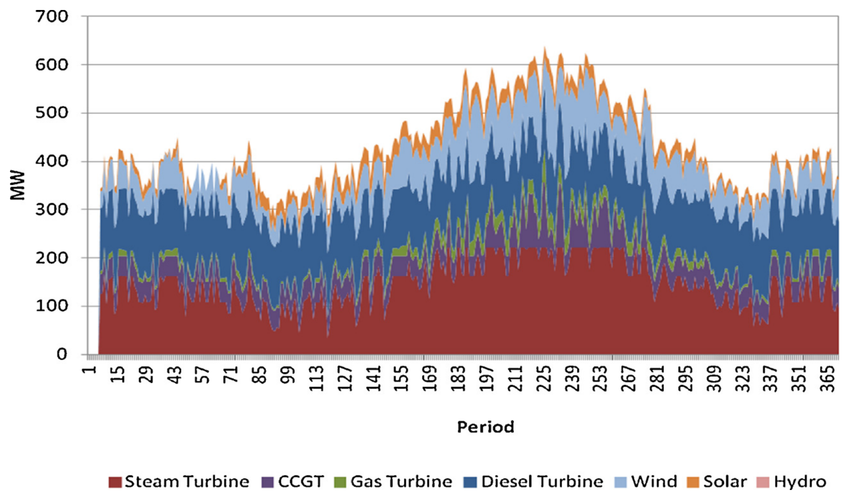

Fig. 1. Average Hourly load profile of Crete per day in 2015 (Hellenic Electricity Distribution Network Operator, 2016).

incentives.

1.1. Overview of Crete's electricity system

Europe counts 362 main islands with more than 50 permanent residents plus 286 with smaller population. Approximately 2% of Europe's population currently is living on them (Eurelectric, 2012). The peculiar case of the Greek system consists of 80 principal islands from which 58 are non-interconnected. The island of Crete is the largest non-interconnected island in Greece, located in the southern part of the Aegean Sea. The capital of Crete, Heraklion, is the fourth largest city in Greece and the whole island utilizes more than 50% of the total power consumed in the Aegean Sea non-interconnected islanding region (Hellenic Electricity Distribution Network Operator, 2014). Crete is the only island in Greece considered a small isolated system since 2014, when the Non-Interconnected Islands (NIIs) Code was entered into force (Hellenic Republic, 2014d). All other Greek NIIs are qualified as isolated micro-systems compliant with Article 2(27) of Directive 2009/72/EC (European Commission, 2014).

Crete recorded annual electricity demand levels of 2.7 TW h (2,693 GW h) and a peak load of 634.3 MW in 2015 (Fig. 1). Electricity demand is covered by three local thermal power plants with a total capacity of 823.46 MW (Table 1). Crete as the plethora of geographically isolated regions across the world, relies predominantly on heavy fuel oil (HFO) and secondly on diesel fuel, which is used to cover peak demand since it records considerably higher prices and increased tax rates. The steam turbines and the CCGT station are mainly used to cover the base load, on the basis of their slow response to demand fluctuations, while gas turbines and diesel engines provide power during the peak hours. Renewable energy sources (RES) represent 23% of the total annual electricity generation, consisting of wind and solar energy (200.3 MW and 78.3 MW respectively) and a small hydropower station (0.3 MW). Other forms of energy such as bioenergy, solar thermal and hybrid technologies have not been exploited yet. Due to the increased use of oil, the carbon emissions intensity factor for Crete is 0.69 t/MWh, which is 15% higher than the average national carbon intensity factor. Crete produces approximately 1.8–1.9 million carbon tones from electricity generation per year.

The average full production cost for Crete was approximately 180.7 €/MWh in 2016 (Hellenic Electricity Distribution Network Operator, 2016). The divergence between power generation costs in the NIIs and the interconnected system price (62.63 €/MWh) is remunerated through the 'Public Service Obligation' (PSO) policy (Hellenic Republic, 2014c). PSO sets a common electricity price for all the Greek electricity consumers pursuant to Laws 3426/2005 and 4001/2011 and is collected by the electricity suppliers through a levy on the electricity bills

Table 1
Technical characteristics of thermal power plants (Hellenic Electricity Distribution Network Operator, 2017a).

Units	Fuel	Capacity (MW)	Retirement Year[a]	Technical Minima (MW)
Linoperamata Power Station				
Steam Turbines - (Annual 2015 Gen.: 330 Gwh)				
Steam 1[b]	HFO	6.25	2011	2
Steam 2 and 3	HFO	15	2017	8
Steam 4, 5 and 6	HFO	25	2021	18
Gas Turbines - (Annual 2015 Gen.: 47 Gwh)				
Gas 1[c] and 2	Diesel	16.25	2013	3
Gas 3	Diesel	43.37	2027	5
Gas 4	Diesel	14.72	2027	3
Gas 5	Diesel	28	2027	6
Diesel Engines - (Annual 2015 Gen.: 292 Gwh)				
Diesel (1-4)	HFO	12.28	2019	3
Chania Power Station				
Gas Turbines - (Annual 2015 Gen.: 46 Gwh)				
Gas 1	Diesel	16.2	2010	3
Gas 2	Diesel	24	2010	5
Gas 3	Diesel	30	2011	5
Gas 4 and 5	Diesel	59.4	2023	10
Gas 6	Diesel	28	2017	8
Combined Cycle Gas Turbines - (Annual 2015 Gen.: 419 Gwh)				
CCGT	Diesel	132.3	2030	35
Atherinolakos Power Station				
Diesel Engines - (Annual 2015 Gen.: 332 Gwh)				
Diesel 1 and 2	HFO	51.1	2034	25
Steam Turbines - (Annual 2015 Gen.: 578 Gwh)				
Steam 1 and 2	HFO	46.5	2047	20
Total Capacity 823.46 MW (including reserves)				

[a] Retirement year will be prolonged in anticipation of the interconnection with the NGS or the introduction of NG (expected year 2020).
[b] Cold reserve mode.
[c] Cold reserve mode.

(Hellenic Republic, 2005, 2011; Regulatory Authority for Energy, 2014). PSO for Crete was configured to 403 Mil €, equivalent to 177.3 €/MWh according to the latest available data (Hellenic Republic, 2014b). Projections show that it could climb up to 600 Mil € for a slow growth scenario (equivalent to 272 €/MWh) and up to 1500 Mil € (equivalent to 370 €/MWh) assuming an aggressive demand and fuel price scenario by 2040 (Zafeiratou & Spataru, 2017). So far, this support scheme has limited the incentives for Crete to innovate in its own electricity system.

Directives 2010/75/EU and 2015/2193/EU have set environmental