Feasibility Study of Energy Storage Systems' Integration in Crete

An IENE Study prepared for the

Independent Power Transmission Operator (IPTO)

Athens, May 2021

Preface

In 2020/2021 the Institute undertook to study on behalf of the Independent Power Transmission Operator (IPTO) of Greece the use of energy storage as part of the local electricity grid on the island of Crete. The timing of the study was not accidental since in 2021 the first leg of the island's interconnection (known as small interconnection) to the mainland grid was completed while the second and much larger is slated for completion before the end of 2023.

The study focuses on Battery Energy Storage Systems (BESS) although planned hydro pumping storage schemes are also taken into consideration.

The study's brief was the examination of the various available options north from a technical and economic view.

What follows is an extended Executive Summary as the full study, which is propriety to IPTO, cannot be released as yet.

Executive Summary

The present study explores the economic feasibility of the integration of Battery Energy Storage Systems (BESS) in Crete in two-time frames, (a) one in 2022 before the commissioning of HVDC cable interconnector Crete-Attica and (b) the other in 2030 after the commissioning of the HVDC interconnector. For the purpose of the elaboration of the analysis the CRETE-UCED+S model was developed, in General Algebraic Modeling System (GAMS) modeling language. It is a mixed integer linear mathematical optimization model, which is solved by CPLEX solver. CRETE-UCED+S model approaches the problem of BESS integration in Crete as a unit commitment problem by simulating the operation of power generation in the electricity control area of Crete and the electricity flows towards and from the interconnected system, minimizing the variable cost of the island's electricity system. On this basis, the model calculates the operational costs of all available power plants, the electricity cost of imported electricity and also estimates the operational benefit of the integration of a technology and capacity specific BESS in the system of Crete. The additional benefits from participation in the balancing market of the Greek interconnected system are not accounted for, as the model comprises the system of Crete.

The analysis explores various scenarios with significant variations of critical parameters: **(a) electricity demand, (b) RES installed capacity, (c) new thermal power capacity (CCGT), (d) New pump hydro energy storage capacity** in Crete**.** Specifically, 2 and 8 unique scenarios were developed for 2022 and 2030 respectively. Moreover, outage events at Crete's interconnectors are also explored for specific scenarios.

Table E1 Simulation scenarios of the integration of BESS in Crete for the reference years, 2022 & 2030

Scenarios for 2022	
BAU22 scenario	HD22 Scenario (HD22(OUT))
Scenarios for 2030	
BAU30 scenario (BAU30(OUT))	HR30 Scenario
PS30 Scenario (PS30(OUT))	CC30 Scenario
HD30 Scenario (HD30(OUT))	HDHR30 Scenario
HDCC30 Scenario (HDCC30(OUT))	HDCCPS30 Scenario

The economic efficiency of BESSs was measured by comparison to the annual depreciation value of their investment, assuming: (a) average expected CAPEX prices of BESS for the reference years, i.e. 2022 and 2030, (b) a lifetime of the BESS investment set at 10 years, (c) no residual value of BESS after the end of the lifetime of the investment, (d) weight average cost of capital (WACC) of 7%, (e) annual operation and maintenance cost of the BESS system, i.e. OPEX, of 0.5% of the CAPEX of the investment and (f) annual depreciation stable throughout the lifetime of the investment.

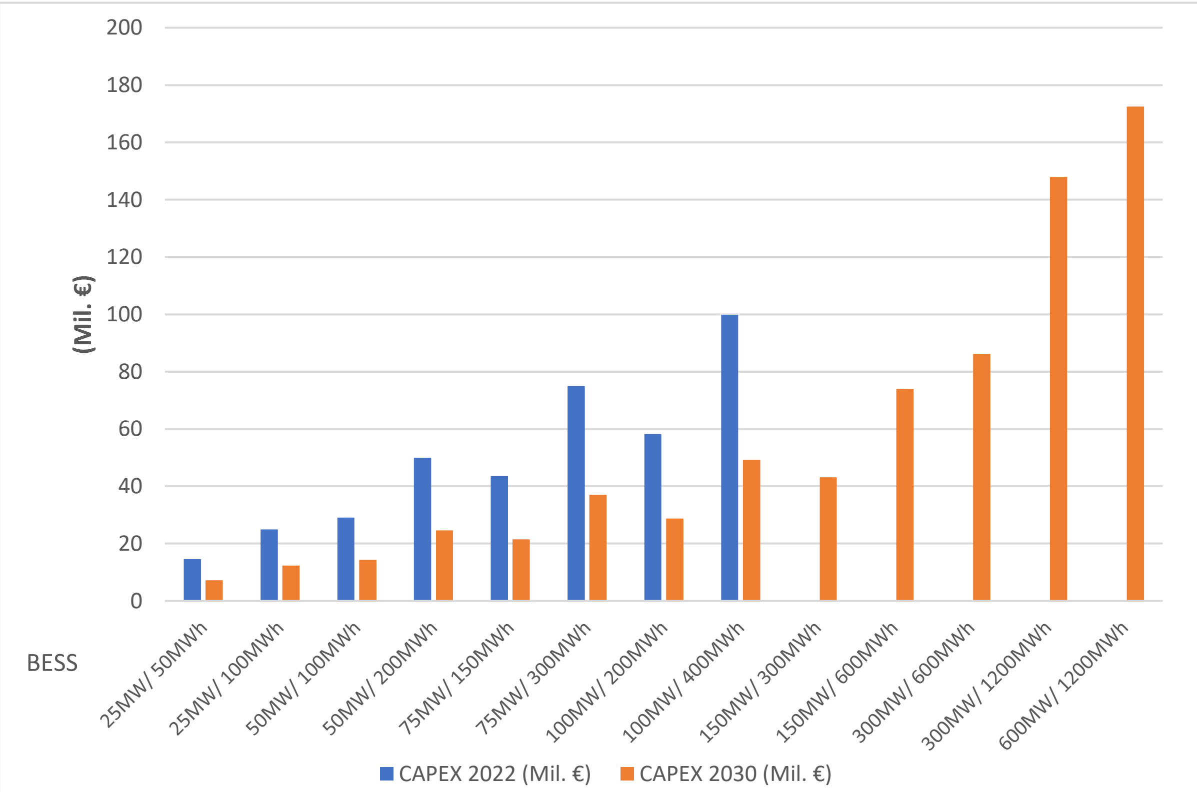

Figure E1 Estimated Capex of examined BESS investment in Crete for the reference years, i.e. 2022, 2030

The analysis shows that the highest economic benefit of BESSs' integration in Crete, is realized in the years prior to the commission of the Crete-Attica HVDC interconnector, when oil power generating units retain a significant share in the electricity mix of Crete. Consequently, the load management (load allocation) performed by integrated BESS capacity can effectively reduce the cost and carbon intensity of the island's power generation by displacing peak load demand to hours, when it can be covered by sources with lower cost and carbon intensity, such as renewables and electricity imports. Specifically, the two major scenarios examined, i.e. **BAU22** and **HD22**, identified a system benefit of €10.5 - €23.6 mil. and €9.3 – 21.7 mil. per year respectively, for BESSs with a storage capacity ranging between 50 MWh and 400 MWh. In the scenario with the lower overall demand in line with the expectations deriving from Greece's NECP, i.e. BAU22, the economic benefit of BESSs' integration is higher by €1.8 – €1.9 mil. due to BESS capacity contributing to the balancing mechanism of the island's system, which is represented as a spinning reserve capacity in the current study, and is required for the smooth operation of Crete's power system.

Moreover, a possible disconnection event of one circuit at the AC interconnector Crete-Peloponnese in the reference year, 2022, under the high demand conditions (**HD22(OUT)** scenario) adds an economic benefit of 4% – 9%, with systems with higher storage capacity exhibiting the higher end of the added value.

If BESSs' integration is examined under the prism of investment viability, projecting the capital cost of BESSs' investment for 2022, the results show that under moderate expectations for the cost of BESSs the most viable BESS storage capacities for investment in the system of Crete are 50MW/200MWh and 50/100MWh for **BAU22** and **HD22** scenarios respectively, offering an economic benefit for Crete's system after depreciation of €12.07 mil. and €10.07 mil. respectively.

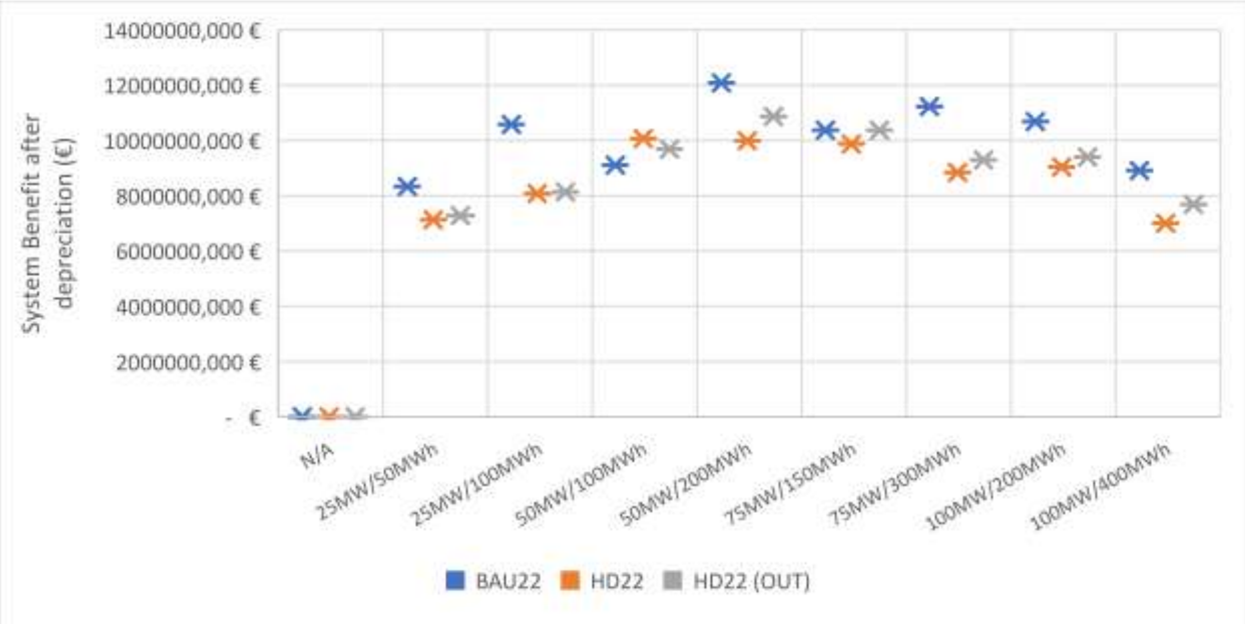

Figure E2 Economic benefit after depreciation for the integration of various BESS in the system of Crete under all examined scenarios

Such a finding practically means that under conditions that define Crete's power system in 2022 (i.e. interconnectivity, available power sources, demand etc.), such BESS investments could reach a break-even point within 3 – 4 years, with significant added value for Crete's system onwards. Therefore, the time accuracy of the commissioning schedule for the HVDC interconnector Crete-Attica will practically define if there is time for adequate depreciation of such investments within the window of time between deployment of a central BESS (2021/2022) and the commissioning date of HVDC cable interconnector, Crete-Attica (expected in 2023).

Some of the economic benefits of BESSs are retained until 2030 but are of significantly lower magnitude than the ones explored for the 2022 scenarios, and are mostly focused on economically efficient arbitrage in electricity transmission between Crete and mainland Greece. Therefore, despite significantly lower costs of BESSs' investment in 2030, depreciation of such investments becomes significantly difficult without a support scheme that will ensure an adequate revenue. However, such a support scheme or a capacity mechanism for Crete would prioritize storage systems with high storage capacity, which can contribute significantly to the Crete system generation adequacy.

More specifically, economic benefits for Crete's system in 2030 after depreciation of the integrated BESS are identified only for low storage capacity systems in the **BAU30** scenario, i.e. ≤100 MWh, in an event of DC pole disconnection at the Crete-Attica interconnector (disconnection was investigated during July-August). The specific event can potentially drive an annual economic benefit of €0.29 – €0.47 mil., for integrated BESS capacities of 50MW/100MWh and 25MW/50MWh respectively. However, disconnection events are not frequently reoccurring, therefore the specific systems are expected to undergo multiple negative cashflows during the lifetime period of the investment under the BAU30 scenario conditions. Furthermore, if battery cost is reduced further than the one projected for the purposes of the present study, systems with higher capacities, i.e. 150 MWh and 200 MWh could become also viable under the DC pole disconnection circumstances underlined in the **BAU30(OUT)** scenario, an event that will also enhance the viability of the smaller systems, as exhibited in FigureE3. However, the positive cashflows indicated in this specific scenario are of significantly lower magnitude than the annual cashflow deficit of the same BESSs in BAU30, indicating that still these investments would require policy support for viability assurance under the scenarios with moderate penetration of variable renewables to Crete's system.

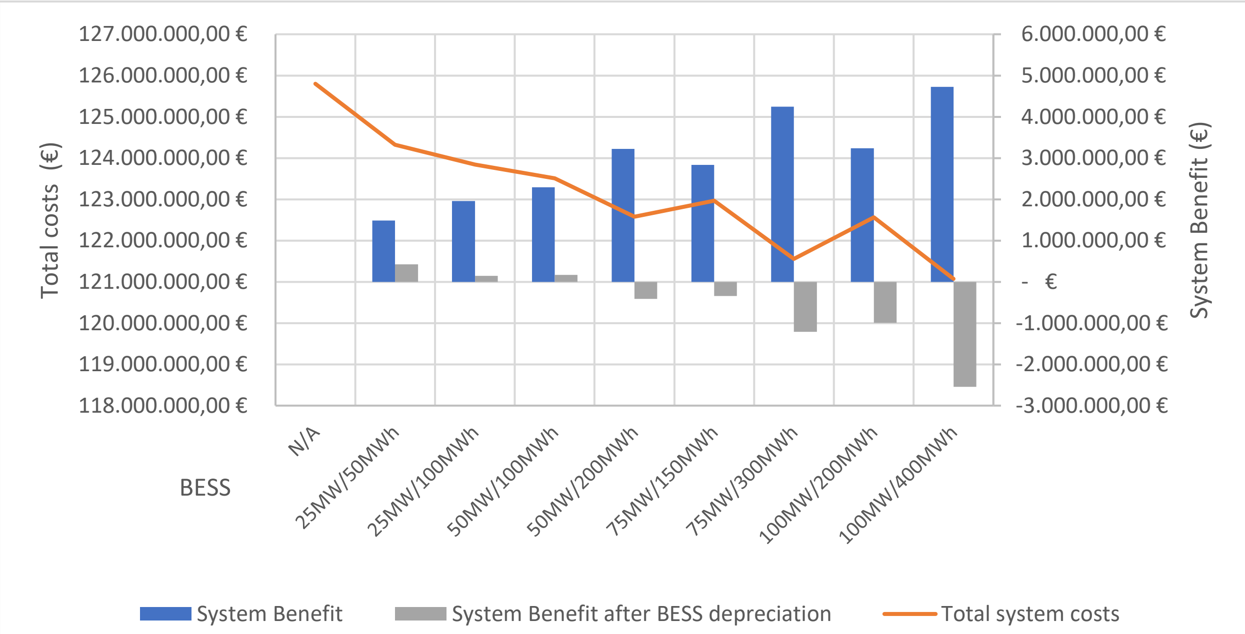

Figure E3 Added economic value of the integration of various BESS, under BAU30(OUT) scenario with weekly BESS SoC setpoint

At small and moderate BESS storage capacities (i.e. 50 MWh – 400 MWh), BESSs are not highly competitive to, nor obstruct the operation of a possibly integrated pumped-storage hydropower unit in operation (i.e. the Amari hybrid power station) under conditions underlined in **PS30** and **HDCCPS30** scenarios, where the DC interconnection is fully available. The added windpower capacity of the hybrid power station of Amari mainly displaces more cost intensive electricity imports from the mainland system, affecting however additionally the utility value of BESS. In case of a DC pole disconnection (scenario PS30(OUT)), the competition between BESS and the hybrid power station is increased, because both technologies compete to trim the low volumes of cost intensive peak loads due to the engagement of local oil and gas units. Comparing to scenario BAU30(OUT), where only the BESS deployment is considered, economic benefits of BESS integration are significantly lower and, thus, even low storage capacity systems (i.e. ≤100 MWh) do not become viable. It is also noted that in scenarios for 2030 reserve needs were neglected, as the DC interconnection is fully available. In case of parallel operation of BESS and the hybrid power station before completion of the DC interconnection, it can be expected that the two systems would compete for providing balancing services.

The integration of an efficient CCGT unit in Crete does not affect significantly the operation of integrated BESS. The overall effect is that the CCGT unit, under the **CC30** scenario acts as seasonal competitive power source to the imported electricity from mainland Greece, reducing overall system cost by approximately €450,000/year in comparison to BAU30 scenario. Consequently, BESSs' economic benefits remain marginally similar to the ones exhibited in BAU30 scenario. Similarly, CCGT's integration in **HDCC30** scenario does not affect the operation of a potential BESS investment, with operational and economic results of the integrated storage systems showing strong similarities with HD30 scenario.

High electricity demand under the **HD30** scenario has little effect on the operation of integrated BESS, with the economic effects of its integration on the system remaining marginally similar to the ones exhibited in BAU30. This can be attributed to the absence of frequent price spikes in mainland Greece, as most expensive imports remain at relatively similar volumes across all scenarios. Overall, higher demand, pushes significantly upwards the share of electricity imports in Crete's electricity mix to 52.5%, while system costs are offset upwards by approximately €28.2 mil. in comparison to BAU30 scenario. In the occurrence of a disconnection event in one of the DC poles at the HVDC interconnector Crete-Attica, under **HD30(OUT)** scenario, all BESS investments examined become viable on an annual level, with economically optimal performance exhibited by Crete's system with the integration of smaller sized systems, with storage capacities of 100 MWh – 200 MWh, which yield an economic benefit after depreciation for the system of €1.8 – €2.6 mil. per year, as exhibited in Figure E4. In addition, this transmission capacity outage also generates a power deficit in Crete's system of approximately 0.43 GWh over 23 hours during the 2-month disconnection period (July-August examined), which can be almost entirely corrected with the integration of BESS, i.e. (a) it can be reduced to 0.11 – 0.18 GWh over a period of 4 - 7 hours for the economically optimal storage capacities of 100 MWh – 200 MWh of integrated BESS and (b) it's completely erased for storage capacities greater than or equal to 400 MWh.

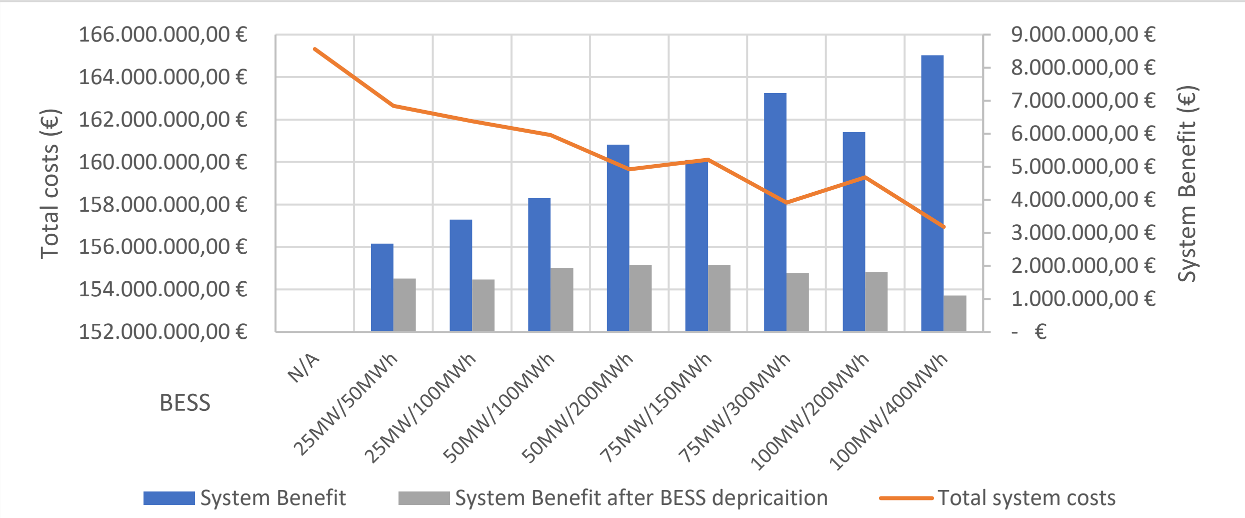

Figure E4 Added economic value of the integration of various BESS, under HD30(OUT) scenario with weekly initialization of BESS's operation

The plausible disconnection event, of one DC pole at the HVDC cable interconnector in conditions of high demand, when competitive gas-fired generation is deployed in Crete, under **HDCC30(OUT)** scenario, does not create a power deficit, as the integrated capacity of CCGT is able to cover peak demand at peak load demand periods during the two-month period of reduced transmission capacity of Crete's interconnectors. As a result, the integration of competitive CCGT capacity reduces the economic utility of a BESS deployment at low interconnectivity conditions by 84.9% - 85.8% (for BESS with storage capacity between 100 – 400 MWh), and drives annual cashflows of the specific investments under these circumstances to negative values.

The current study also explores the role of BESSs in RES curtailment reduction in outlined cases with high penetration of variable renewables, particularly wind, i.e. in the **HR30** and **HDHR30** scenarios. In the specific scenarios 2.55 GW of installed renewable generation (1.8 GWh of windpower) leads to significant generation curtailment from variable renewables, which reaches to 9.17% and 7.82% of potential RES generation or 623 GWh and 532 GWh for scenarios HR30 and HDHR30 respectively, without the integration of a central BESS in Crete. Consequently, significant contributions of BESS have been identified in reducing the curtailed power generation from variable renewables (see Figure E5). These were estimated at approximately 100 MWh of reduction of curtailed electricity generated from renewables per year for every 1 MWh of BESS storage capacity integrated, for BESS with storage capacity ranging from 100 MWh to 600 MWh for HR30 scenario with similar results also exhibited also in the HDHR30 scenario. At higher capacities the effective reduction of curtailed generation from variable renewables per MWh of BESS storage capacity introduced declines proportionally to the magnitude of storage capacity integration. Indicatively, a BESS with capacity of 300MW/600MWh can reduce RES curtailment by 9.75% and 10.93% for HR30 and HDHR30 scenarios respectively, which corresponds to 101 MWh and 97 MWh of RES curtailment reduction per MWh of BESS storage capacity integrated per year.

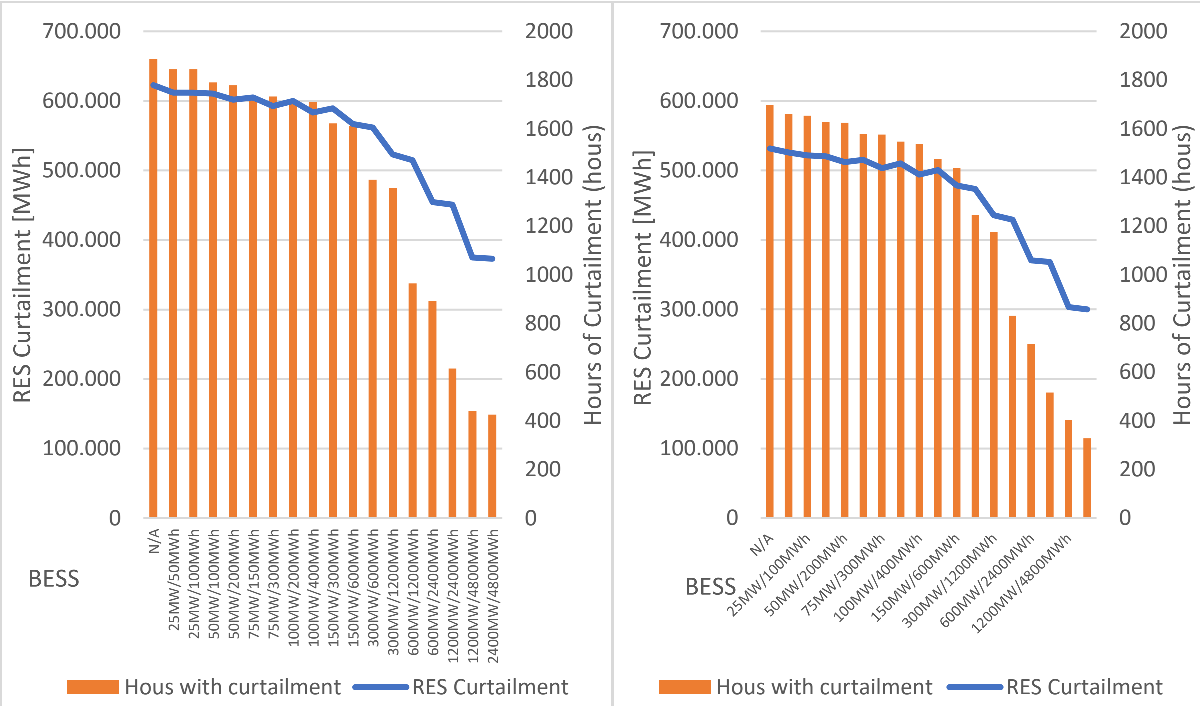

Figure E5 Estimation of curtailment of RES (MWh) and annual accumulated time (hours) of RES's curtailment for scenarios (a) HR30 and (b) HDHR30 for the integration of various BESS in Crete.

The realization of BESSs' integration in economic terms under the perspective of high-RES penetration in Crete should be evaluated for a system cost reduction that derives from the savings of curtailed generation from RES under an assumed levelized cost of electricity (LCOE) for mixed renewable generation. Effectively this system cost reduction would reflect the differential between projected market clearance prices for the interconnected system, at the reference year, and an LCOE for the curtailed generation from renewables, which is not analyzed in the present study.

Acronyms and Abbreviations

A/C	Air Conditioning
AC	Alternating Current
AGM	Absorbent Glass Mat
Ah	Ampere hour
BESS	Battery Energy Storage System
BMS	Battery Management System
DC	Direct Current
DOD, DoD	Depth of Discharge
ESS	Energy Storage Systems
LFP	LiFePO – Lithium Iron Phosphate
LTO	LiTiO – Lithium Titanate Oxide
NaS	Sodium – Sulphur
NMC, NCM	LiNiMnCo – Lithium Nickel Manganese Cobalt
OPzS	Ortsfest PanZerplatte Flüssig (stationary, tubular plate, flooded battery)
OPzV	Ortsfest PanZerplatte Verschlossen (stationary, tubular plate, valve regulated battery)
PCS	Power Conditioning Systems
PV	Photovoltaic
PWM	Pulse Width Modulation
RES	Renewable Energy Sources
SLA	Sealed Lead Acid
SLI	Starting, lighting and ignition
SOC, SoC	State of Charge
TRL	Technology Readiness Level
VRB, VRFB, VFB	Vanadium Redox Flow Battery
VRLA	Valve Regulated Lead Acid