IENE

WEBINAR

APRIL 27

THE ROLE OF ENERGY STORAGE
IN ADVANCING LARGE SCALE RES PENETRATION

“Feasibility Study of Energy Storage Systems’ Integration in Crete”

IENE WEBINAR: THE ROLE OF ENERGY STORAGE IN ADVANCING LARGE SCALE RES PENETRATION

A Presentation by A. Perellis, Researcher, IENE

INSTITUTE FOR ENERGY FOR
SE EUROPE

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- Scope of the study
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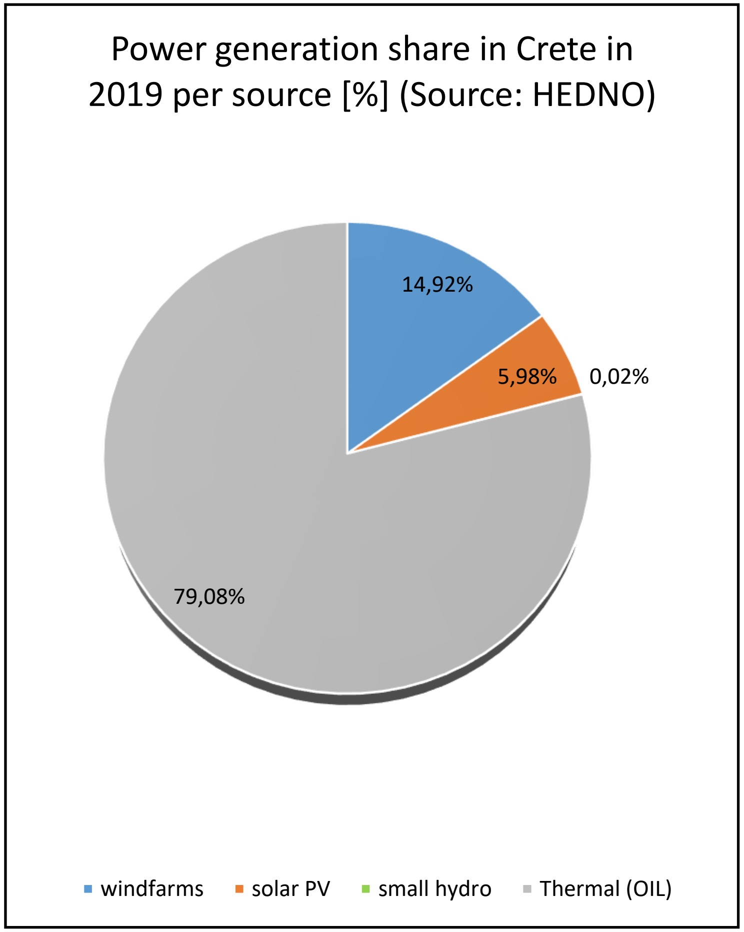
Introduction – Current condition

- Crete depended on Oil for its power generation by 79.08% in 2019, or 2.44 TWh .
- EU Directives 2010/75/EU (IED) and 2015/2193 are in effect, expected to lead to withdrawal the oil-fired power generating units in Greece's island systems.
- Currently there are 24 oil-fired power generating units in Crete, with installed capacity of approximately 708 MW located in three sites: Hania, Atherinolakkos and Linoperamata.
- AC interconnector Crete-Peloponnese expected during 2021



Future Outlook

- DC interconnector (2x500 MW) Crete Attica
- Considerations for conversion Atherinolakos Steam turbine units 1 & 2, for use of natural gas.
- 11 units have or will obtain derogation from IED
- Retirement of 16 units with total installed capacity of 318 MW by 2026.
- Considerations for installation of a new efficient CCGT (250 MW)

Scope of the study

- Scope of the analysis is to identify the economic (and environmental) benefits of the introduction of energy storage systems in Crete. It is a study that was elaborated on behalf of IPTO.

- Assessed technology: lithium-ion Battery Energy Storage Systems (BESS)

- Two reference years 2022 and 2030
  - 2022:
    - The system cost optimization (power generation and reserves)
    - The reduction of oil use in Crete
  - 2030:
    - Reduction of RES curtailment
    - Maximization of Economic benefit from arbitrage
    - Cost reduction under adequacy concerning circumstances (certain generation and interconnector capacities available)

Scenarios I

10 Unique Scenarios: variation of critical parameters:

(a) electricity demand,

(b) RES installed capacity,

(c) new thermal power capacity (CCGT),

(d) New pump hydro energy storage capacity

2022 :

- Deployed Peloponnese – Crete AC interconnector (MVA)
- Examination of two electricity demand profiles
- Assessment of BESS in an event of circuit disconnection at AC interconnector under a high electricity demand conditions (indicated with connotation OUT)

BAU22 scenario	HD22 Scenario
• Scheduled decommissioning of conventional diesel and fuel oil units (2022) • RES penetration in line with NECP (2022) • A/C Interconnector Crete-Peloponnese is available • Demand as foreseen by NECP (2022)	• Scheduled decommissioning of conventional diesel and fuel oil units (2022) • RES penetration in line with NECP (2022) • A/C Interconnector Crete-Peloponnese is available • Demand is higher than the one foreseen by NECP (2022)

Scenarios II

2030:

- Deployed DC interconnector Attica – Crete
- Examination of two electricity demand profiles
- Examination of two RES generation profiles
- Assessment of BESS with/without the deployment of Amari hybrid power station (pump storage unit)
- Assessment of BESS with/without the deployment of an efficient Gas-fired CCGT
- Assessment of BESS in an event of a DC pole disconnection at DC interconnector under various conditions (indicated with connotation OUT)

BAU30 scenario	HR30 Scenario
• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand in line with NECP (2030)	• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration higher than the one foreseen in NECP (2030) * • Demand in line with NECP (2030)
PS30 Scenario	**CC30 Scenario**
• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand in line with NECP (2030) • Includes the Amari RES hybrid station	• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand in line with NECP (2030) • New installed CCGT unit burning Natural gas with installed capacity 250 MW
HD30 Scenario	**HDHR30 Scenario**
• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand is higher than the one in line with NECP (2030)	• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration higher than the one in line with NECP (2030) * • Demand is higher than the one foreseen by NECP (2030)
HDCC30 Scenario	**HDCCPS30 Scenario**
• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand is higher than the one foreseen by NECP (2030) • New installed CCGT unit burning Natural gas with installed capacity 250 MW	• Scheduled decommissioning and conversion of conventional diesel and fuel oil units (2030) • AC Interconnector Crete-Peloponnese and DC Interconnector Crete-Attica are available • RES penetration in line with NECP (2030) * • Demand is higher than the one foreseen by NECP (2030) • New installed CCGT unit burning Natural gas with installed capacity 250 MW • Includes the Amari RES hybrid station

* Includes the Minos – Solar-Thermal Power plant in Sitia

Methodology - CRETE-UCED+S model

- Crete UCED+S model developed by IENE
  - Mixed-integer linear programming tool.
  - Cost optimization (minimization).
  - Deterministic model.
- Crete-UCED+S model : tailormade for the elaboration of the specific study.
- Input
  - Thermal cycle of available thermal units (ramp-up/down, min up/down time, technical minimum output etc.)
  - Grid constraints: spatial constraints, spinning reserves etc.
  - RES generation (deterministic time series)
  - Electricity Demand (deterministic time series)
  - Costs: generation costs (variable costs, start-up/down costs, RES curtailment costs, cost of imported electricity (deterministic time series), etc.)
  - Battery operation constraints (initialization set points, maximum DoD, roundtrip efficiency)
- Output
  - Estimation of the electricity generation mix (generation from dispatched units and electricity flows at interconnectors)
  - System cost (optimized)

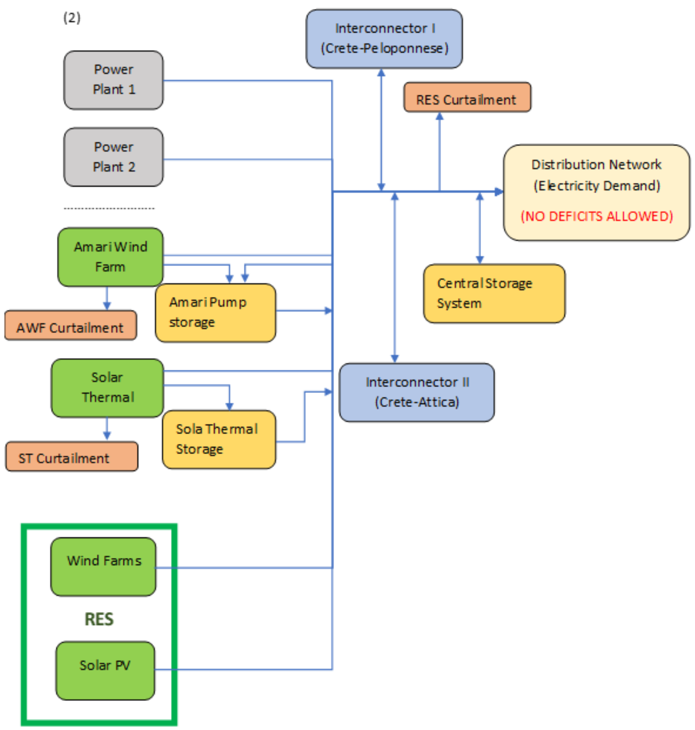


Figure 2 Nodal depiction of CRETE-UC+S model's function for the 2030 scenarios (Note: the display of thermal power plants in the nodal diagram (in grey) is indicative)

Parameters and assumptions utilized in the analysis

- RES
  - Cost of curtailment (1 €/MWh)
  - Time series projections (IPTO)

Scenario	Year	Wind	Solar PV	Solar CSP
Reference	2022	221	135	0
	2030	322	302	50
High RES	2022	-	-	-
	2030	1800	700	50

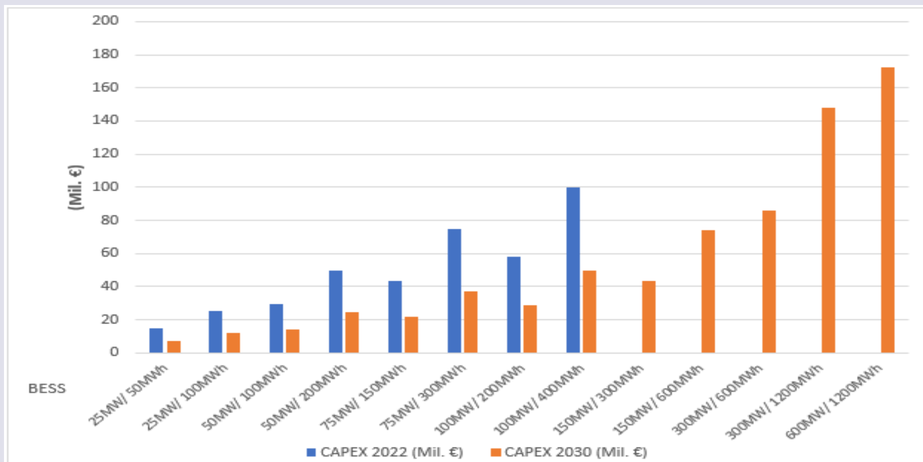
  - Amari hybrid power station with PS (75 MW (output), 140.16 MW pumping capacity, 1087.7 MWh storage capacity)

- Electricity demand: Time series projections (IPTO)

Scenario	Reference		Higher Demand	
Year	**2022**	**2030**	**2022**	**2030**
MAX load [MW]	667	733	728	827
Total [GWh]	3105.683	3410.646	3386.547	3847.526

- Power deficit is not Allowed
- Generation Costs: Projections for the costs of operation, i.e. variable costs and startup/shutdown costs for each unit expected to be operational in the reference years (IPTO)
- Electricity prices in mainland Greece: Time series projections (IPTO)
- Available Capacity of interconnectors (under disconnection event)
- Grid Constraints (affecting generation schedule)

- BESS
  - Roundtrip efficiency: 90%
  - Maximum allowed DoD 85%
  - CAPEX – average expected prices (2022, 2030)
  - Investment lifetime 10 years (no residual value)
  - WACC 7%
  - OPEX 0.5% of CAPEX



BESS integration in 2022 – Results BaU22

- BAU22 Scenario: Reduction of oil use in Crete
  - 100MW/400MWh : -5.6% power generation from oil units
  - 100MW/400MWh: -73.2% of thermal units start ups
  - 50MW/200MWh: €12.07 mil. after depreciation

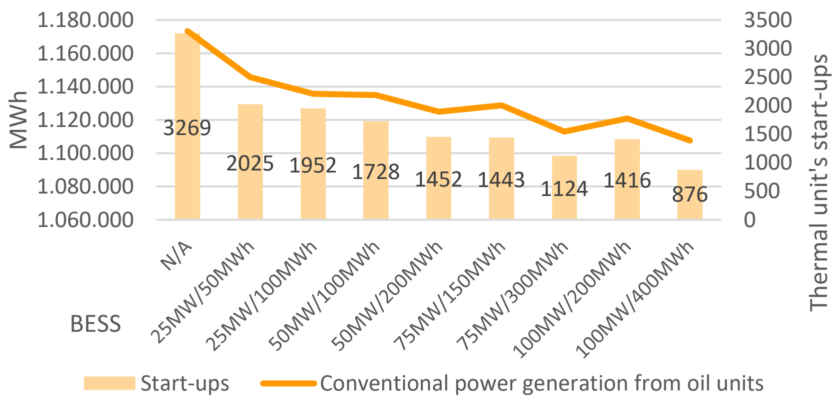


Figure 5 Power generation from conventional oil units in Crete for BAU22 scenario after the integration of various BESS.

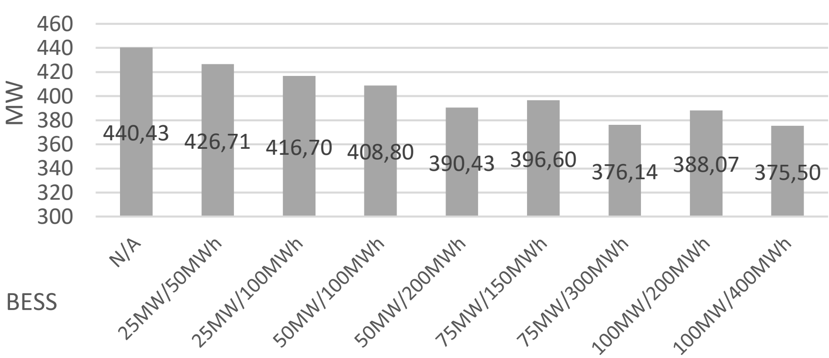


Figure 4 Annual maximum hourly average load demand covered by conventional oil units in Crete for BAU22 scenario after the integration of various BESS.

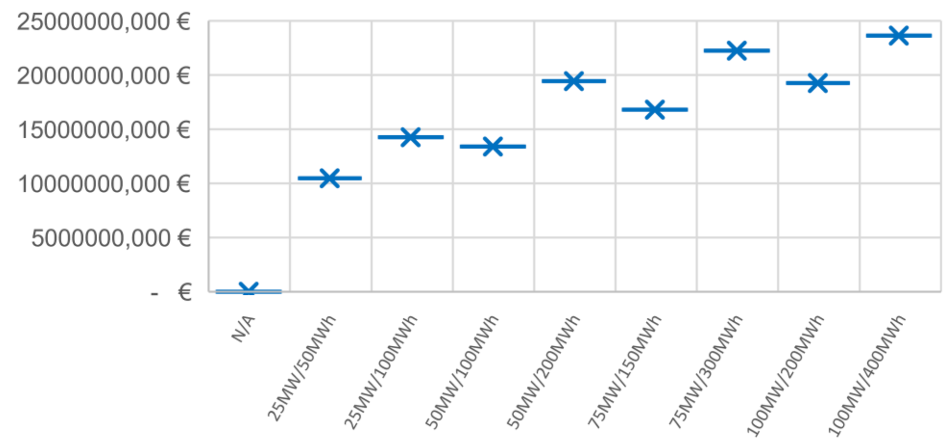


Figure 2 Economic benefit for the integration of various BESS in the system of Crete under BaU22 Scenario

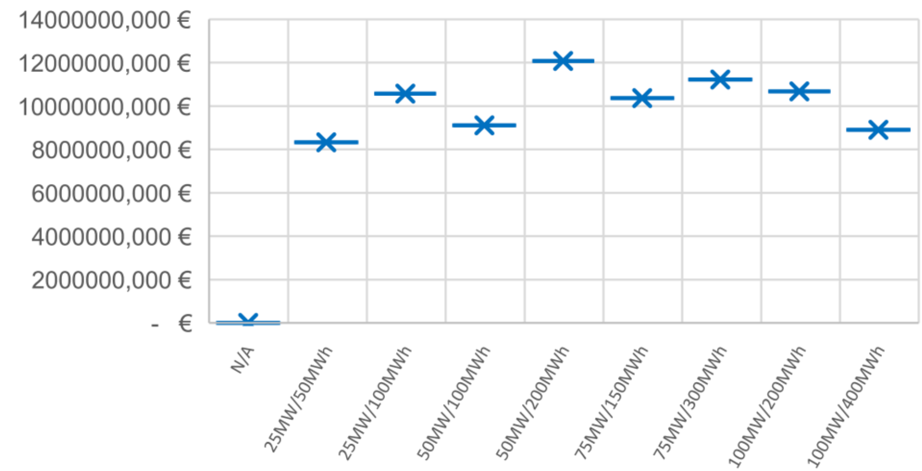
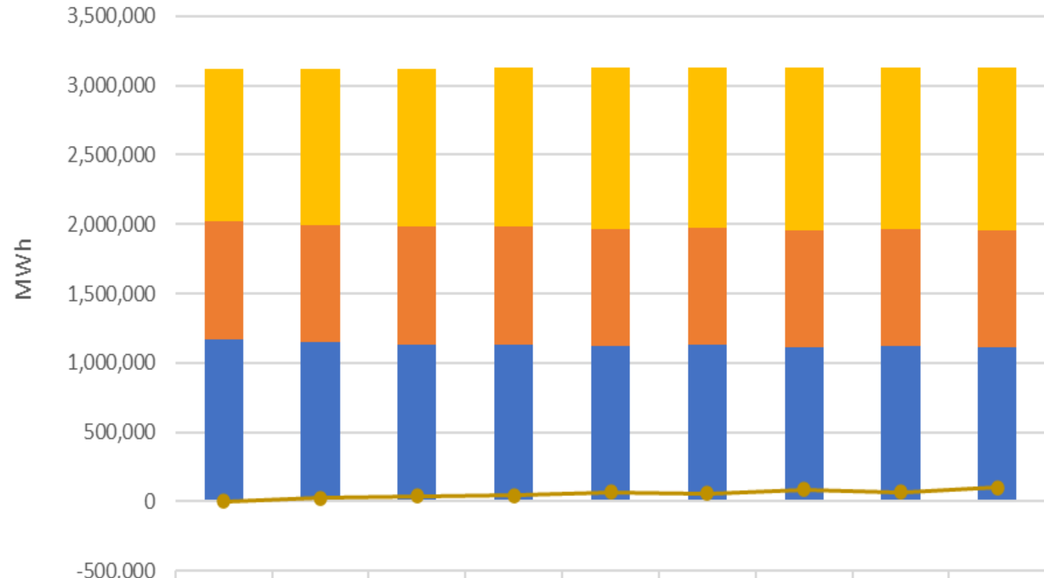


Figure 3 Economic benefit after depreciation for the integration of various BESS in the system of Crete under BAU22 scenario

BESS integration in 2022 – Results BaU22 II

- Increase of electricity imports of Crete (2.74% - 7.13%, or 30.14 GWh – 78.56 GWh) for BESS 25MW/50MWh – 100MW/400MWh

- Increasing electricity exports at capacities ≥75MW



BESS	N/A	25MW/ 50MWh	25MW/ 100MWh	50MW/ 100MWh	50MW/ 200MWh	75MW/ 150MWh	75MW/ 300MWh	100MW/ 200MWh	100MW/ 400MWh
Curtailment	0	0	0	0	0	0	0	0	0
Exports	-5879	-5277	-5105	-5424	-5495	-5905	-6075	-6588	-7262
Imports	1102131	1132271	1143578	1145147	1157698	1153392	1172234	1163046	1180687
Gas	0	0	0	0	0	0	0	0	0
RES	843595	843595	843595	843595	843595	843595	843595	843595	843595
Oil	1173468	1145690	1135688	1134944	1124862	1128736	1113060	1120946	1107710
Battery Discharges	0	26680	39968	44523	66099	58526	85493	69160	102730

BESS integration in 2022 – Results HD22

- HD22 Scenario: Reduction of oil use and generation cost reduction in Crete
  - 100MW/400MWh : -12,8% power generation from oil units
  - 100MW/400MWh: -74% of thermal units start ups
  - 50MW/100MWh : Optimal; €10.07 mil. after depreciation

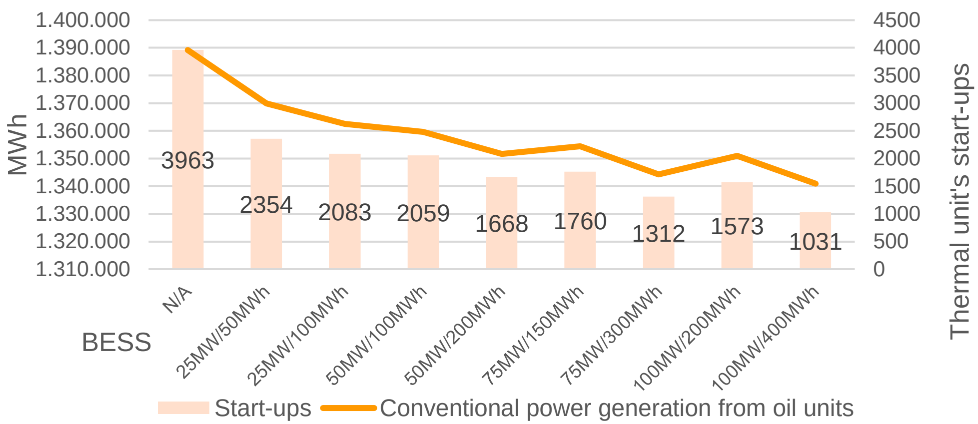


Figure 8 Power generation from conventional oil units in Crete for HD22 scenario after the integration of various BESS.

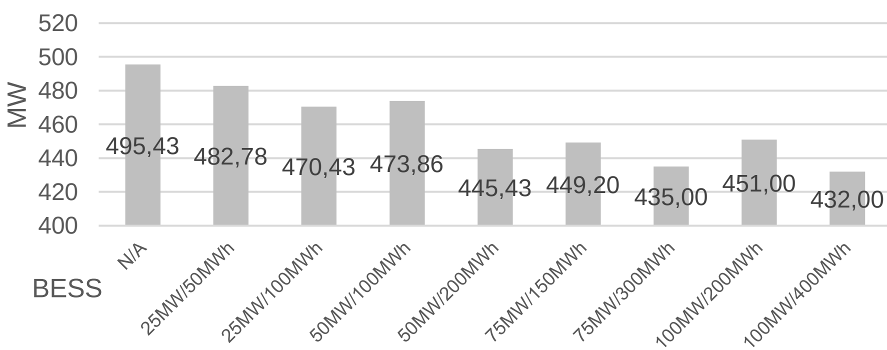


Figure 7 Annual maximum hourly average load demand covered by conventional oil units in Crete for HD22 scenario after the integration of various BESS.

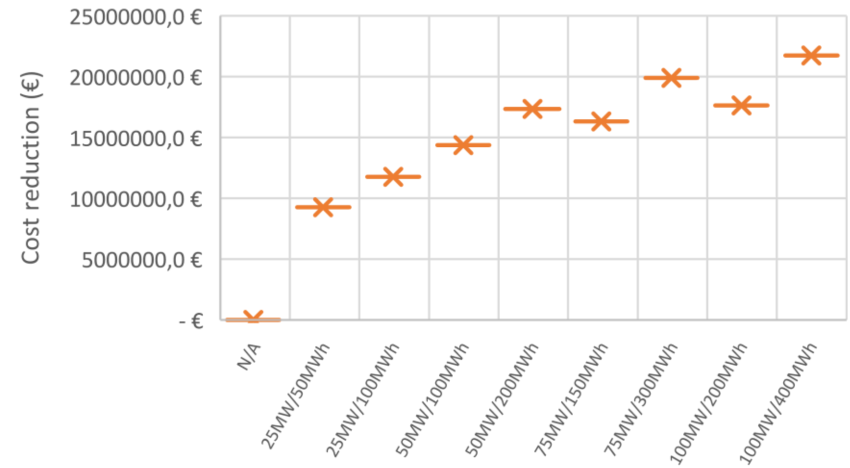


Figure 2 Economic benefit for the integration of various BESS in the system of Crete under BaU22 Scenario

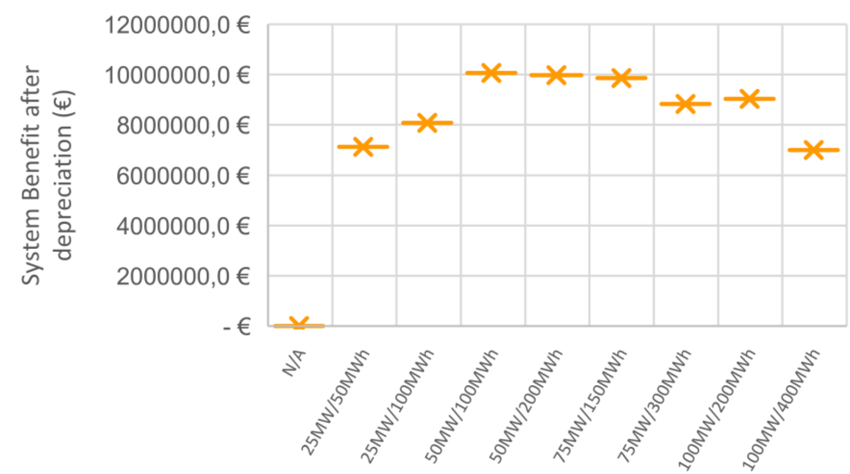


Figure 3 Economic benefit after depreciation for the integration of various BESS in the system of Crete under all examined scenarios

BESS integration in 2022 – Results HD22 (OUT)

- HD22(OUT) Scenario: Reduction of oil use in Crete
  - 100MW/400MWh : -9.9% power generation from oil units
  - 100MW/400MWh: -74% of thermal units start ups
  - 50MW/200MWh : Optimal; €10.86 mil. after depreciation

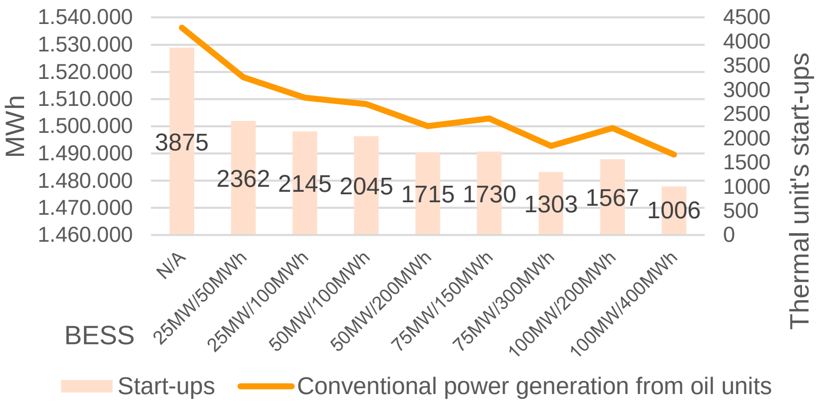


Figure 10 Power generation from conventional oil units in Crete for HD22(OUT) scenario after the integration of various BESS.

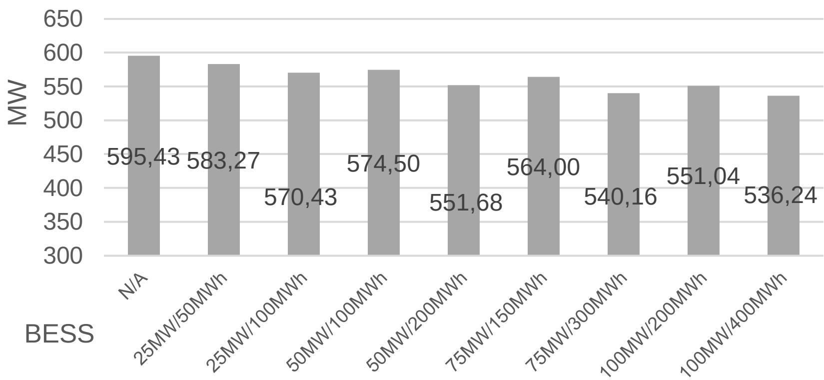


Figure 11 Annual maximum hourly average load demand covered by conventional oil units in Crete for HD22 scenario after the integration of various BESS.

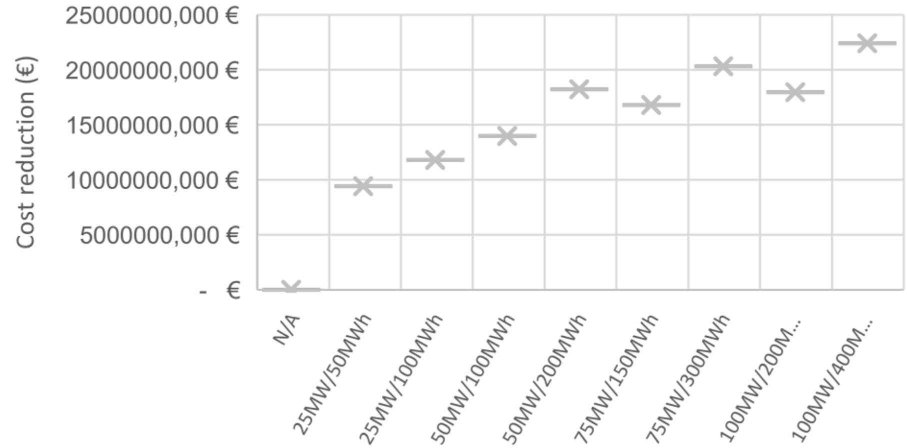


Figure 2 Economic benefit for the integration of various BESS in the system of Crete under all examined scenarios

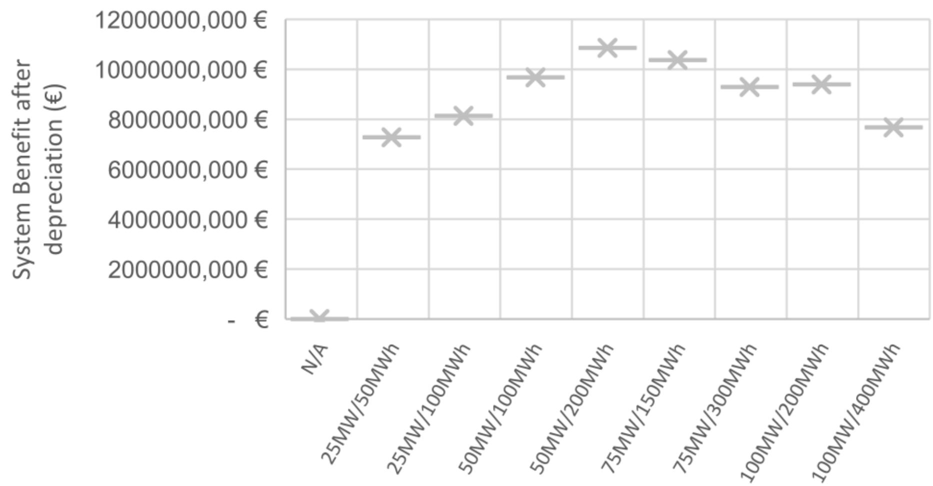
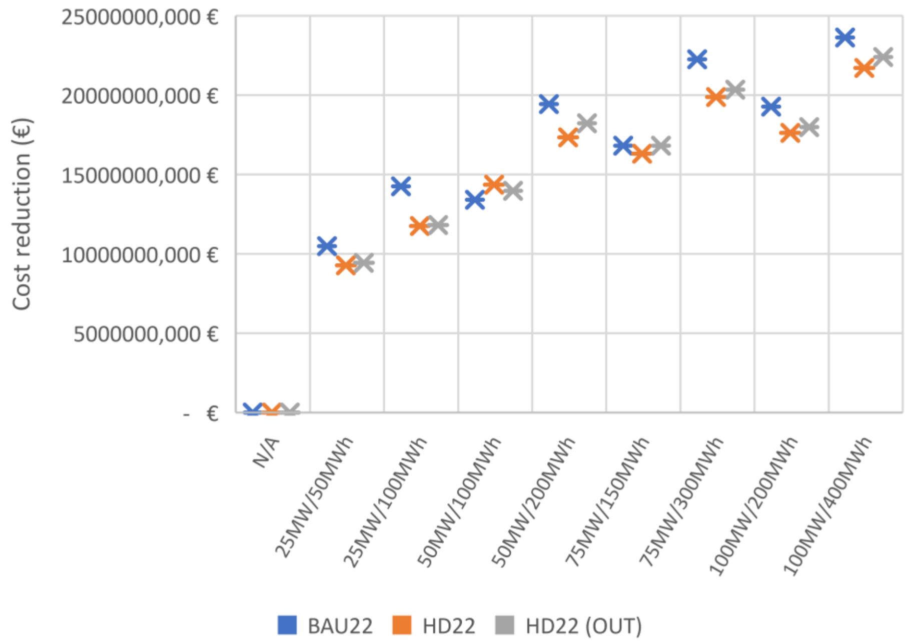


Figure 3 Economic benefit after depreciation for the integration of various BESS in the system of Crete under all examined scenarios

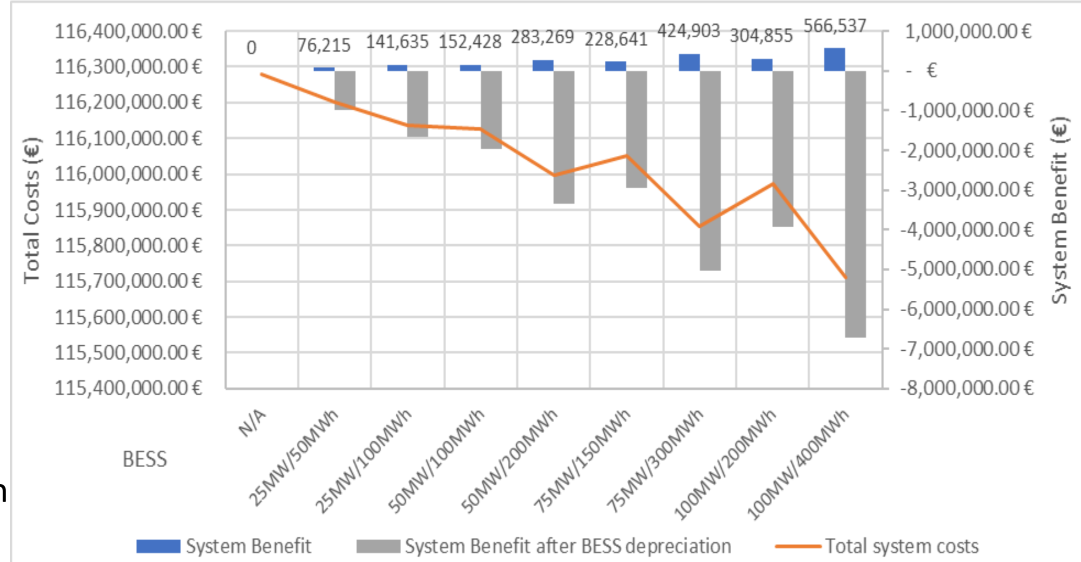
Comparative Results of BESSs' economic feasibility for 2022

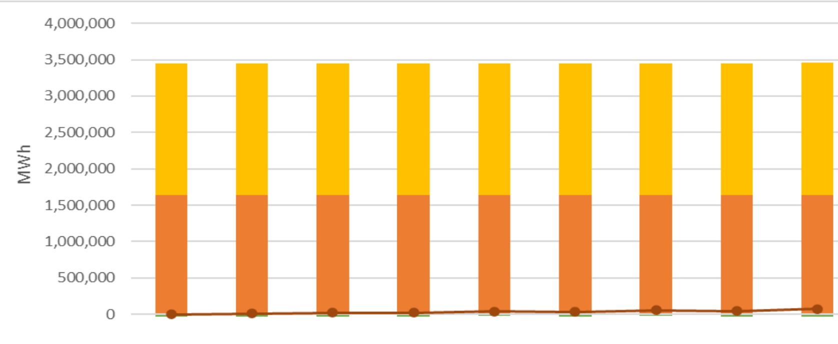


- System benefit BAU22 : €10.5 - €23.6 mil. for BESS storage capacity ranging between 50 MWh and 400 MWh
- System benefit HD22 : €9.3 - €21.7 mil. for BESS storage capacity ranging between 50 MWh and 400 MWh
- Higher benefit of BESSs' integration is higher by €1.8 – €2.1 mil. due to BESS capacity contributing to the spinning reserves.
- disconnection event of one circuit at the AC interconnector Crete-Peloponnese during a period of high demand (July-August) adds an economic benefit of 4% – 9% (Scenario HD22)

BESS integration in 2030 – Results BaU30

- 47.54% of the demand in the system of Crete or 1.64 TWh annually is covered by RES
- 52.46% or 1.81 TWh is covered by electricity imports.
- Oil units and gas retrofitted units at Atherinolakkos TPP remain in cold reserve.
- Less use of BESS in comparison to 2022 driven only by arbitrage (price volatility of imported electricity from mainland Greece) . Indicatively BESS annual utilization is lower by: 25MW/50MWh: -59.58% or -15.9 GWh 100MW/400MWh: -29.2% or -30 GWh
- Low system benefit €76,215 - €566,537 for BESS 50 MWh – 400 MWh.
- Negative cashflows after depreciation: 25MW/50MWh: € -0.98 mil. 100MW/400MWh: € -6.7 mil.





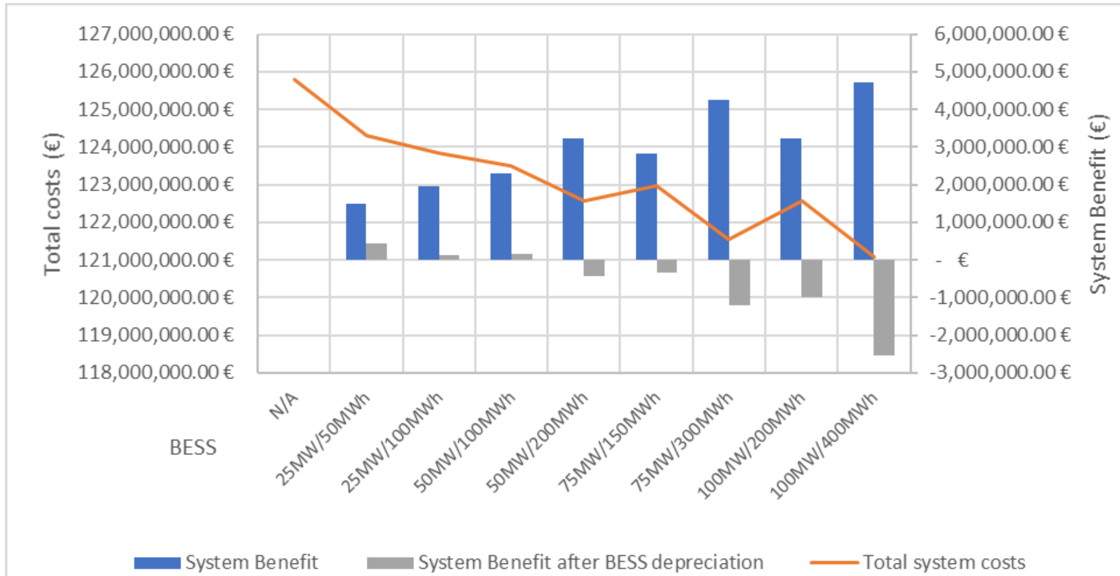
BESS	N/A	25MW/ 50MWh	25MW/ 100MWh	50MW/ 100MWh	50MW/ 200MWh	75MW/ 150MWh	75MW/ 300MWh	100MW/ 200MWh	100MW/ 400MWh
Curtailment	0	0	0	0	0	0	0	0	0
Exports	-30202	-29420	-28540	-29162	-27619	-29190	-27951	-30115	-29526
Imports	1809295	1809712	1809663	1810636	1810758	1811850	1813108	1813970	1816701
Gas	0	0	0	0	0	0	0	0	0
RES	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937
Oil	0	0	0	0	0	0	0	0	0
Battery Discharges	0.00	10784	18267	21419	36414	32097	54573	42857	72731

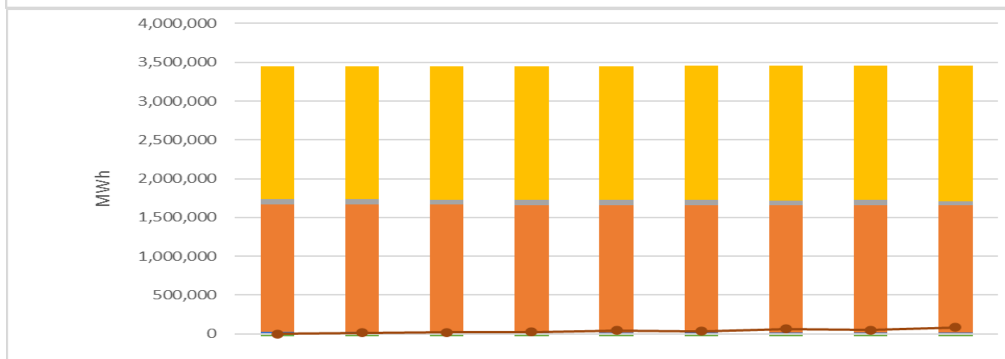
BESS integration in 2030 – Results BaU30 (OUT)

- temporal load allocation adds system utility value of 1.48-1.53 mil. € for 25MW/50MWh, and 4.73-5.31 mil. €

- BESS ≤ 100MWh are economically viable after depreciation:
  - 25MW/50MWh, €423-€471 thousand per year
  - 25MW/100MWh, €141-€247 thousand per year
  - 50MW/100MWh €171-€294 thousand per year

- BESS ≥ 150 MWh: negative cashflows after depreciation

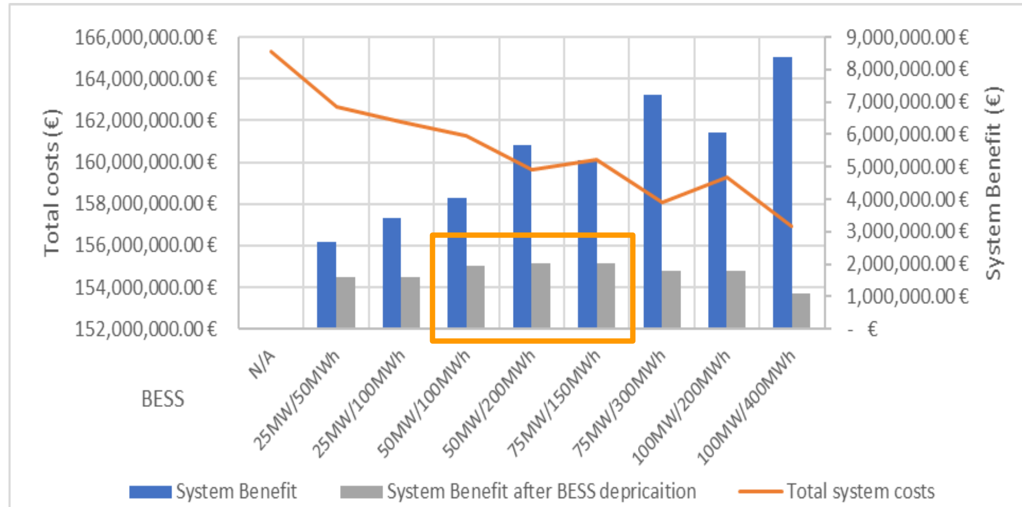


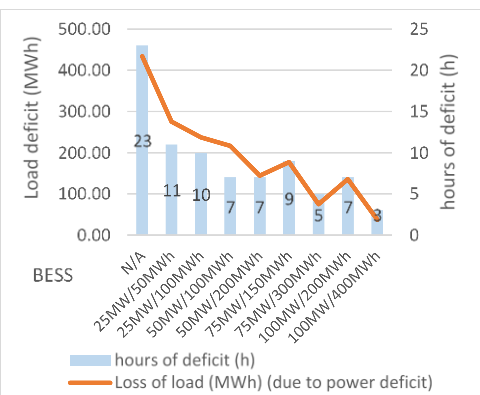


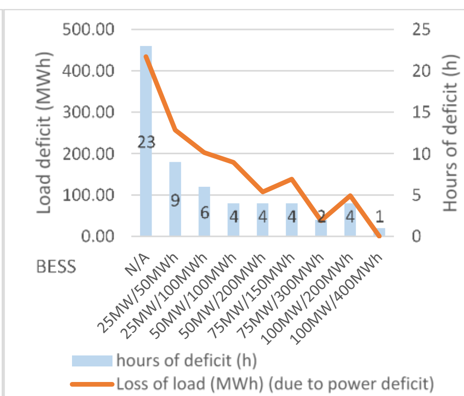
BESS	N/A	25MW/ 50MWh	25MW/ 100MWh	50MW/ 100MWh	50MW/ 200MWh	75MW/ 150MWh	75MW/ 300MWh	100MW/ 200MWh	100MW/ 400MWh
Curtailment	0	0	0	0	0	0	0	0	0
Exports	-30202	-29420	-28540	-29162	-27619	-29210	-27971	-30135	-29536
Imports	1710922	1715565	1719145	1720631	1726342	1726125	1735520	1730895	1746480
Gas	67349	68977	67169	67864	65983	66017	62157	63628	55697
RES	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937
Oil	31004	25413	23765	22562	19190	20287	16517	20167	15887
Battery Discharges	0.00	12977	22017	25214	43230	37135	64169	49148	84911

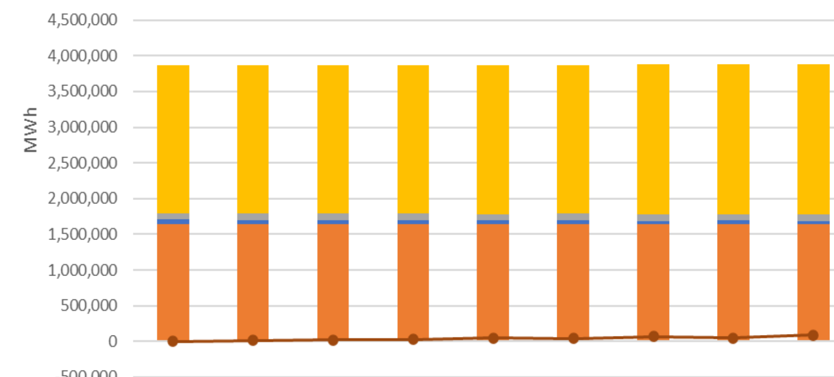
BESS integration in 2030 – Results HD30 (OUT)

- HD30: little effect of BESS, marginally similar results with BAU30 scenario
- Economic benefit after depreciation for systems with storage capacities 100 MWh – 200 MWh€: 1.8 – €2.6 mil. per year
- Power deficit of 0.43 GWh over 23 hours during the 2-month disconnection period (July-August examined)
  - reduced to 0.11 – 0.18 GWh over a period of 4 - 7 hours for 100 MWh – 200 MWh of BESS integrated capacity
  - Almost completely erased for storage capacities greater than or equal to 400 MWh









BESS	N/A	25MW/ 50MWh	25MW/ 100MWh	50MW/ 100MWh	50MW/ 200MWh	75MW/ 150MWh	75MW/ 300MWh	100MW/ 200MWh	100MW/ 400MWh
Curtailment	0	0	0	0	0	0	0	0	0
Exports	-12247	-11788	-11442	-11778	-11078	-12094	-11863	-12637	-12330
Imports	2074873	2081221	2084731	2084433	2089349	2088221	2095468	2091300	2101302
Gas	84848	87596	87175	90272	90891	91685	92589	92455	92506
Oil	69141	61279	58907	56817	52660	53325	48026	51379	45061
RES	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937	1639937
Battery Discharges	0	13808	23035	26199	44254	38381	65209	50246	85730

BESS integration in 2030 – Results HR30 & HDHR30

- System of Crete - Exporting position
- RES curtailment without BESS: HR30: 9.17% (623 GWh) HDHR30: 7.82% (532 GWh)
- HR30: 100 MWh of RES curtailment for every 1 MWh of capacity integrated (for capacities 100 – 600 MWh)
- HDHR30: similar results to HR30 scenario
- Higher capacities – lower effective reduction of RES curtailment
- Highly volatile RES profile: high BESS capacity requirement for significant reduction of RES curtailment.
- E.g. 300MW/600MWh can reduce RES curtailment by 9.75% and 10.93% for HR30 and HDHR30 scenarios respectively (60.74 GWh and 58.15 GWh respectively)
- Economically infeasible.

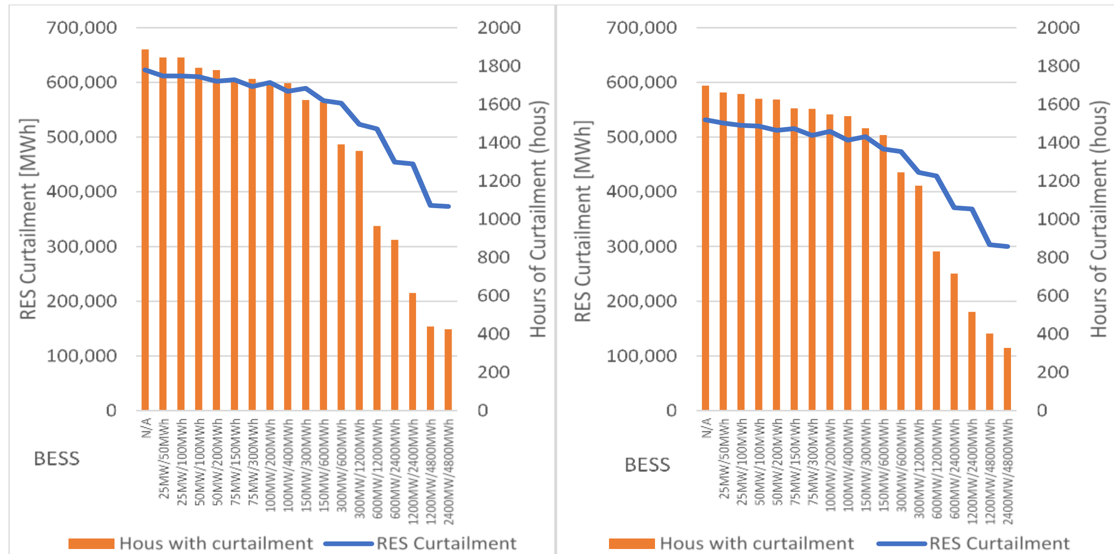
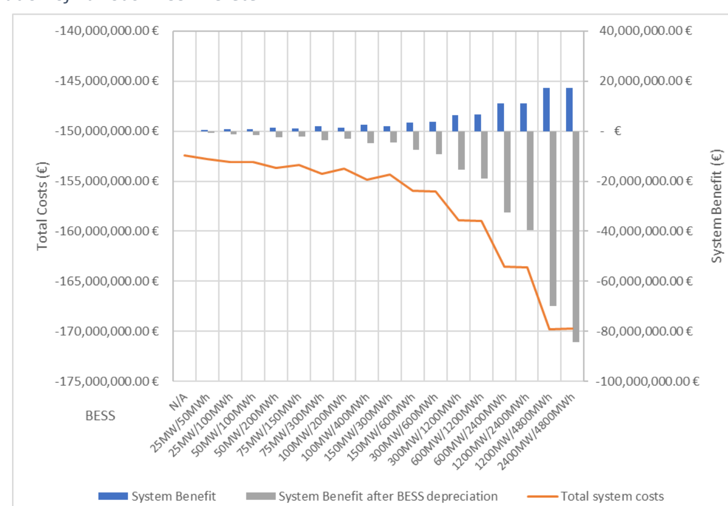


Figure E5 Estimation of curtailment of RES (MWh) and annual accumulated time (hours) of RES's curtailment for scenarios (a) HR30 and (b) HDHR30 for the integration of various BESS in Crete.

Figure 41 Added economic value of the integration of various BESS, under HDHR30 scenario (negative total costs stand for net electricity exports)



RES and demand profile for HR30 & HDHR30

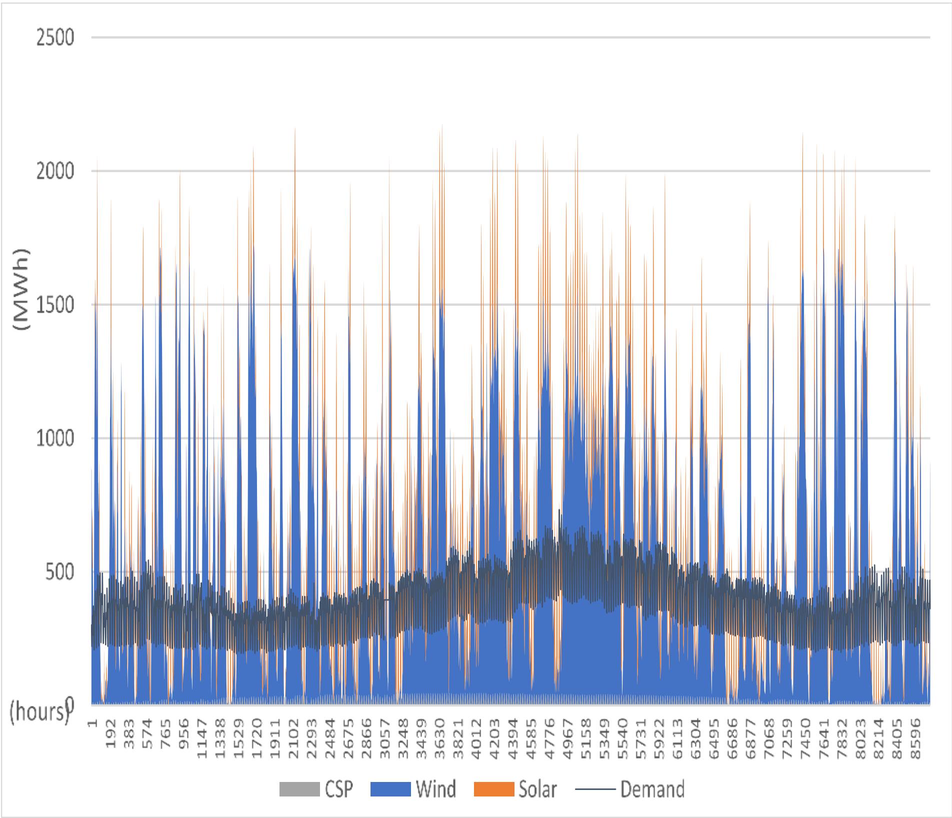


Figure 1 Power generation from RES and electricity demand profile for HR30 scenario.

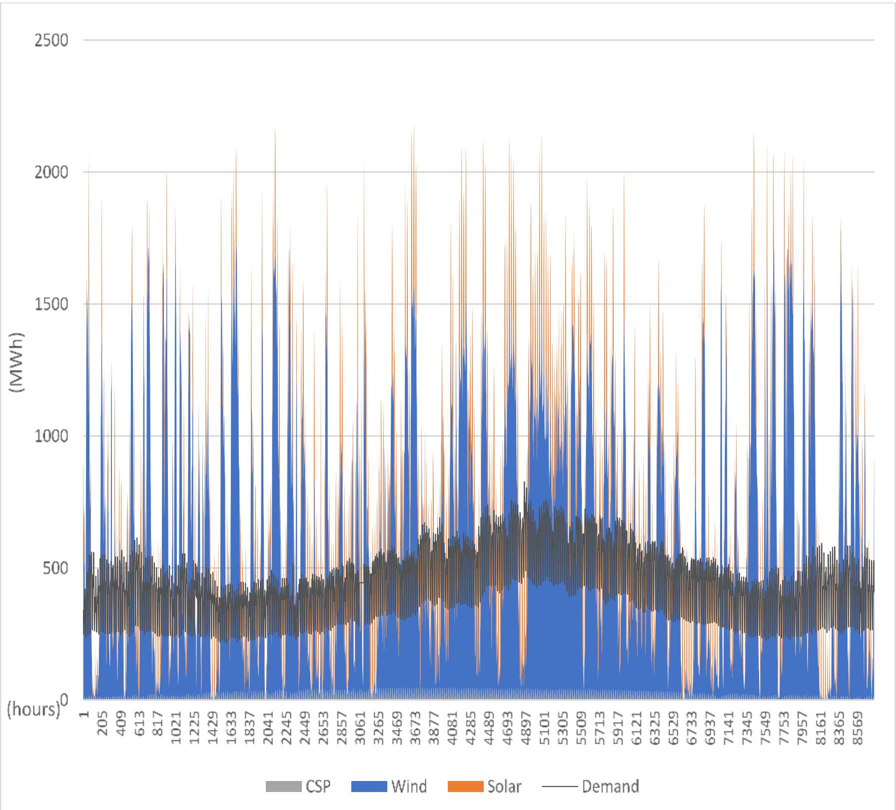
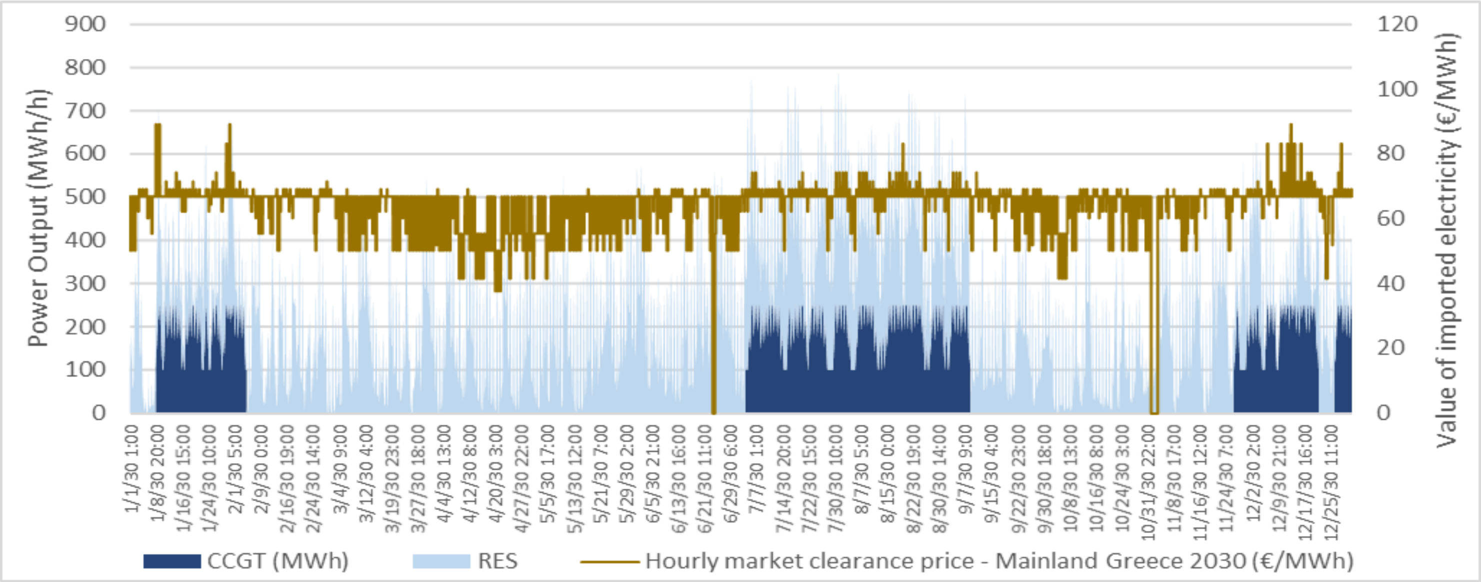


Figure 1 Power generation from RES and electricity demand profile for HDHR30 scenario.

Remarks for other scenarios for 2030 I

- **Integration of BESS of any capacity under all scenarios in 2030 is proven economically infeasible for normal interconnectivity conditions (i.e. no cable disconnection event)**
- 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.



- 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.

Remarks for other scenarios for 2030 II

- 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. (i.e. PS utilization remains similar to prior the integration to 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.

- 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 (PS) before completion of the DC interconnection, it can be expected that the two systems would compete for providing balancing services.

Conclusions

- Economic feasibility of BESS based on projected CAPEX can be found mostly in 2022 when oil units are still the main source of electricity in Crete, and therefore the displacement of their output with RES and imported electricity yields higher economic benefits.
- The economically optimal BESS has been identified to be a BESS with capacity 50MW/200MWh, which can provide economic benefit to the system i.e. system cost reduction after depreciation, of €12.07 mil. and €9.98 mil. for scenarios BAU22 and HD22 respectively.
- A lower demand profile increases the economic feasibility of BESS as their value for provision of ancillary services (spinning reserves) increase. This value is identified to be on the range of €1.8 – €2.1 mil. per year.
- Central BESSs' integration is economically infeasible due to very high investment capital costs in 2030 and low economic benefit from arbitrage.
- Economic feasibility occurs in 2030 under circumstances of an event of one pole disconnection at DC cable interconnector Attica-Crete (2 months) for BESS storage capacities ranging from 50MWh - 100MWh for BAU scenario and for any integrated BESS storage capacity under increased demand conditions
- RES Curtailment occurs only under a high RES integration scenario that includes aggregated RES capacity of 2,550 MW in Crete (RES curtailment of 9.17% and 7.82% or 622 GWh/year and 532 622 GWh/year). In this case there utility value of BESS but still BESS integration remains economically infeasible.
- BESS with high storage capacity are required to reduce drastically curtailment under conditions of high RES penetration.
- The evaluation of reduction of RES curtailment should be made based on a speculative system cost reduction based on an estimation of the difference of LCOE of RES or the value of their participation in the organized market minus the estimated cost of electricity they displaced (not elaborated in the current study)

INSTITUTE OF ENERGY
FOR SOUTH-EAST EUROPE

Thank you very much for your attention!

www.iene.gr

aperellis@iene.gr

aperellis@gmail.com