Techno-economic analysis of electricity storage solutions for isolated power systems

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EMPOWER Workshop on electricity storage in Cyprus, new technologies and challenges

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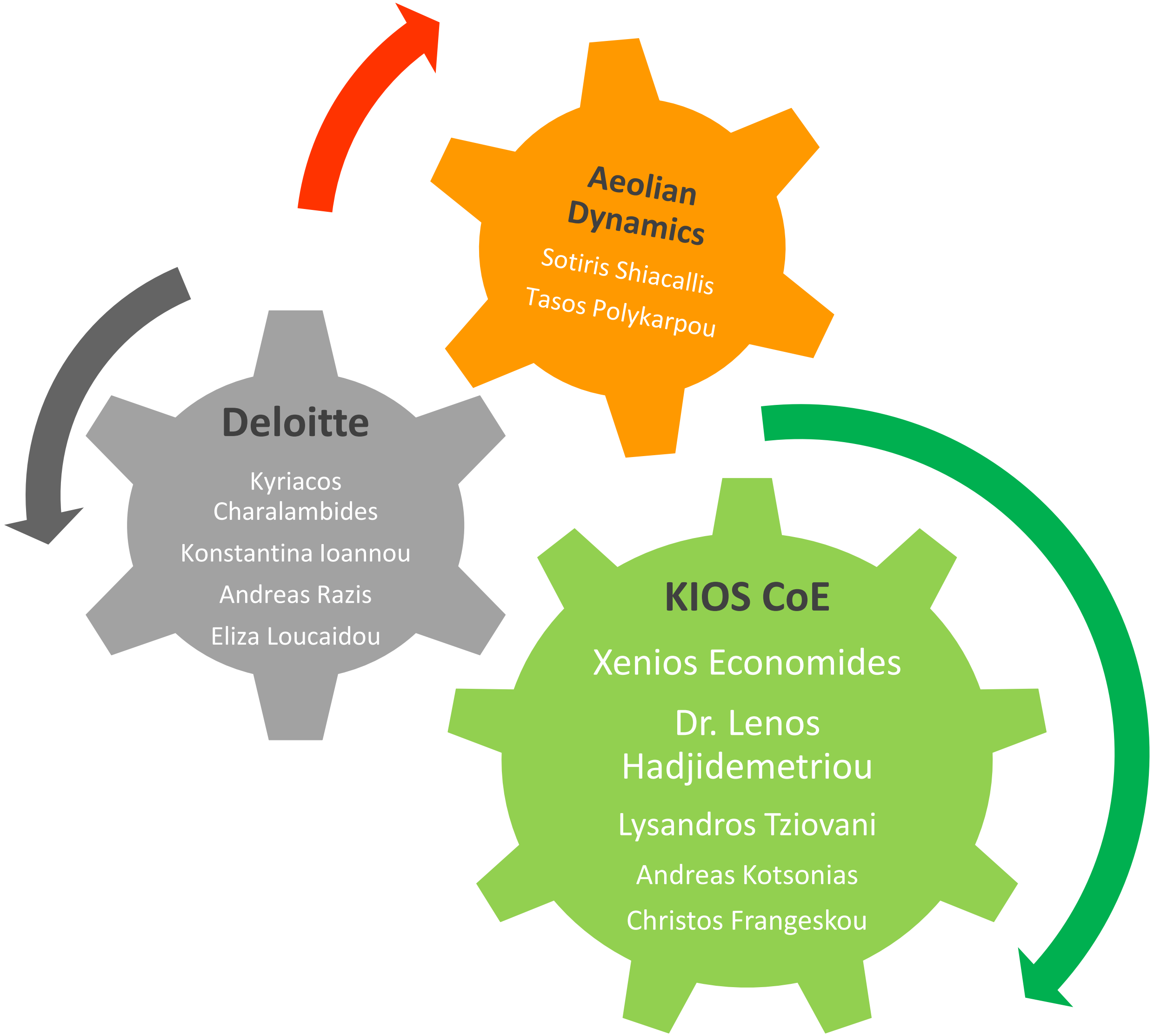
Contributors



Presentation Overview

- Scope of the study
- Methodology overview. Framework design
- Identification of the Case of Cyprus
- Methodology for ranking market available storage technologies
- Methodology for valuation of ESS at grid level (UpM)
- Methodology for valuation of ESS at prosumer level (BtM)
- Conclusions

Scope of the study

Perform techno-economic analysis to identify the most suitable storage technologies for the isolated power system of Cyprus such that to allow the system to reach the country’s RES targets.

Methodology overview

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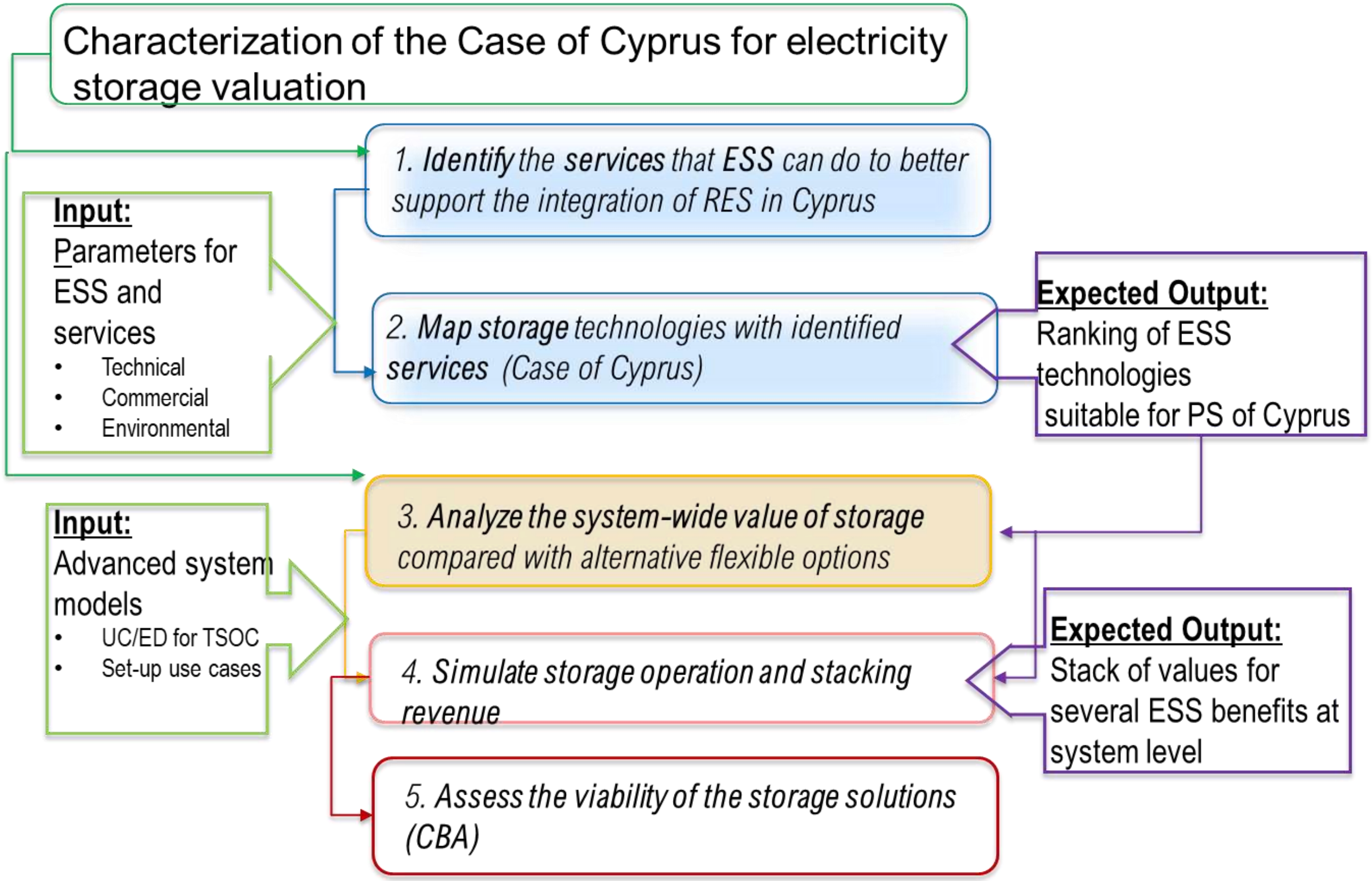
- Identify the Case of Cyprus:
  - Definition of **Baseline scenario (before storage) – reference year 2018**
  - Scenarios 2020 to 2030 (RES and conventional, fuel type/price)
  - How the ESS will affect these scenarios?
    - operation and economic challenges
- Identify where the Costs VS Benefits come from
  - perform ranking of market available ESS technologies
  - Define the life-time of the project (propose **10 years** to be in line with the NDP)
  - **Estimate COSTS** (capital, operation, maintenance, disposal) and
  - **Evaluate BENEFITS** (services)
- Run System Models (UC/ED with and without ESS) to quantify Costs and Benefits at grid level
  - Define scenarios and set-up use-cases
  - Perform CBA to valuate ESS
- Run ESS operation at prosumer level for net-metering VS net-billing scenarios
  - Perform NPV to valuate distributed ESS

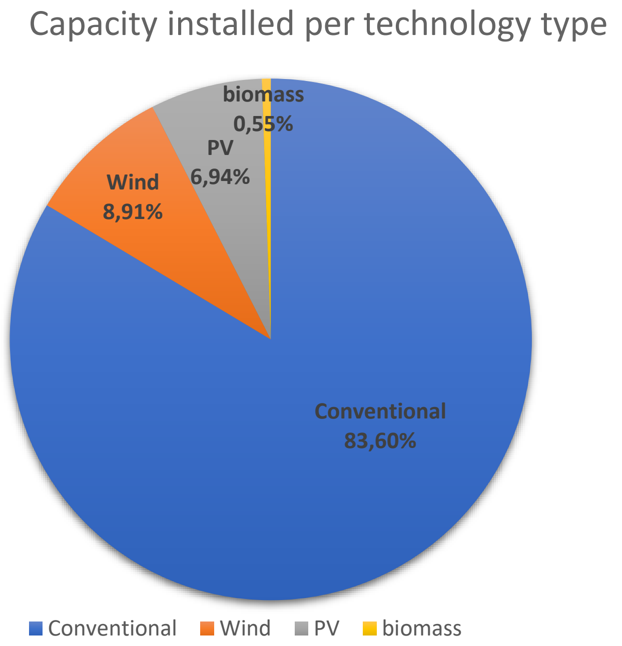
Methodology overview. Framework design

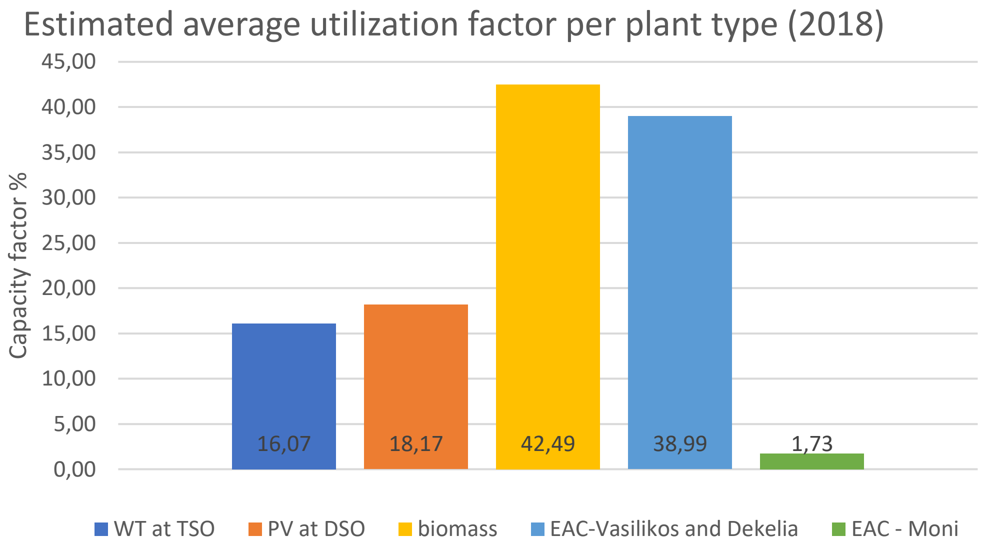


[1] IRENA, ‘Electricity Storage Valuation Framework: Assessing system value and ensuring project viability’, International Renewable Energy Agency - IRENA, Abu Dhabi, United Arab Emirates, ISBN : 978-92-9260-161-4, Mar. 2020.
[2] ENTSO-E, ‘3rd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects’, European Association of Transmission System Operators - ENTSO-E, Brussels, Belgium, Jan. 2020.

Identify the Case of Cyprus

- Baseline scenario (before storage) – reference year 2018:
  - Generation Mix and utilization factor per plant type





EAC Stats 2018:

Fuel cost
€395,76 per metric tonne.
€ 415,7 million
23% increase (2017)

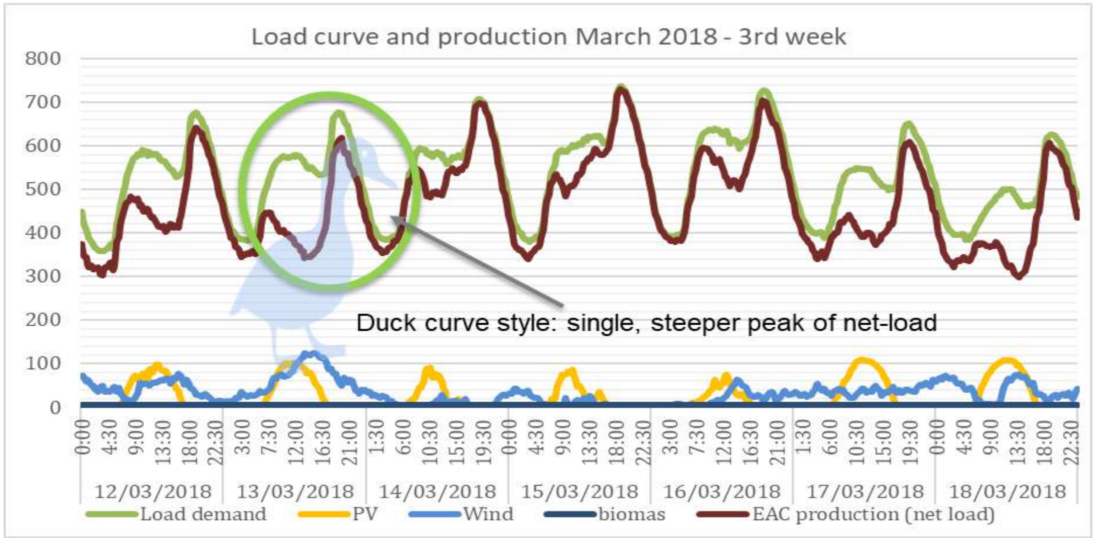
Fuel consumption
1,05 million metric tone **(5026 GWh)**

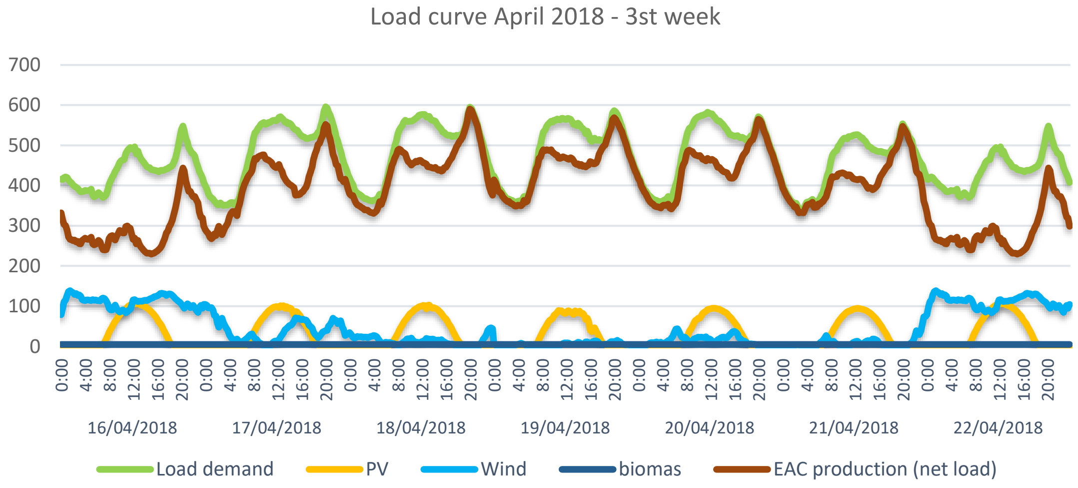
CO2 allowance
~ € 38,5 million
€15,99/allowance
(€6,03/alw in 2017)
~9,3% of the fuel cost

[3] EAC, 'Electricity Authority of Cyprus Annual Report 2018', Nicosia, Cyprus, Jun. 2019.

Identify the Case of Cyprus

Operation challenges at transmission level

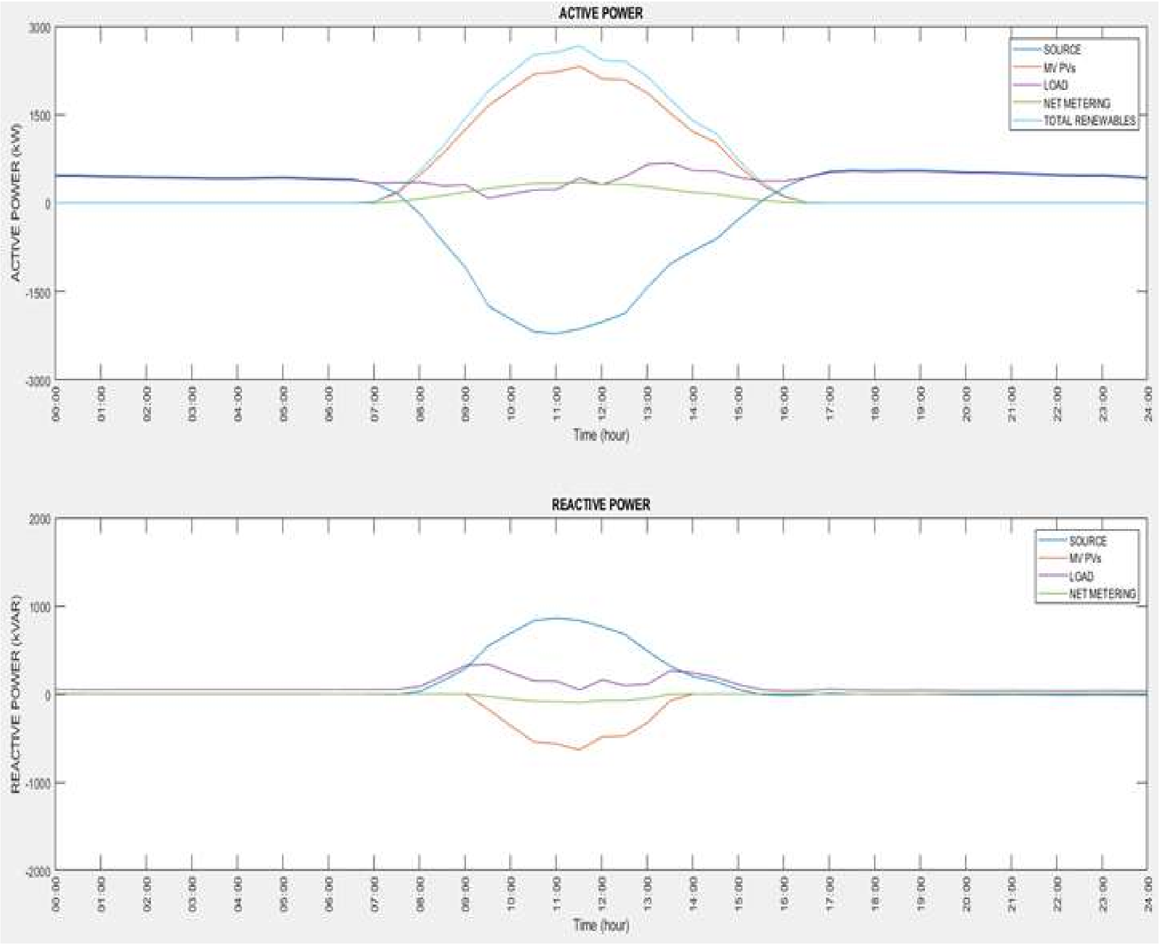




- Steep ramping & operation close to minimum stability margins -> Inefficient operation (higher CO_2 emission/MWh)
- Possible need for curtailment of RES (<1% annually)
- Revenue issues for both RES generation and conventional power plants owners;
- Hard to predict price variations in the electricity markets.
- Storage could participate in system ramping, thus avoiding operation close to stability margins
- Storage could reduce the need for total system reserve (mitigate part of the RES uncertainty)
- Storage could participate in peak shaving

Identify the Case of Cyprus

Operation challenges at the boundaries between TSO and DSO



Kophinou-Muskita MV Feeder: profiles of active and reactive power for one day in January 2018 (from a KIOS study for EAC)

- MV industrial type feeder in the Larnaka district
- ~ 4MW PV (net metering program)
- significant amount of reversed power flow
  - voltage rises at the PVs PCC
  - voltage drop towards the source
  - possible need for PV curtailment if thermal limits reached
- storage system could provide peak shaving
- Storage could participate in the voltage control of the feeder

Identify the Case of Cyprus

Operation challenges at LV side of the DSO

Voltage profile of the LV Lymbia feeder:
current situation with 5% PV penetration
b) near future operation with 30% PV penetration and 3 electric vehicles (from a KIOS study for EAC)

- LV radial feeder in the district of Nicosia
- 5% PV penetration, net metering program
- significant amount of reversed power flow
  - Over voltage near the limits or exceeding (2 out of 3 phases)
- In a 30% PV penetration scenario reverse power flow will often exceed the operation limits during the noon hours
- A hybrid PV-ESS system would eliminate all voltage violations, enhance local-RES self consumption, while further offer several grid support functionalities

Identify the Case of Cyprus

- Scenarios and assumptions for 2020-2030
  - Assume no interconnector is operational on the study period
    - this is a limitation of the study, assumed due to lack of data for modeling the operation of the other power systems
  - Projections in line with the TSOC and according to the National development plan on climate change (2019)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Load demand (GWh)	5243	5372	5501	5630	5759	5887	5937.4	5987.8	6038.2	6088.6	6139
PV capacity (MW)	360	380	400	420	440	460	480	500	523	673	804
Wind capacity (MW)	158	158	180	198	198	198	198	198	198	198	198
Solar Thermal (MW)	0	0	50	50	50	50	50	50	50	50	50
Biomass (MW)	17	22	27	32	37	42	47	50	50	58	58

[4] Republic of Cyprus, ‘Cyprus’ Draft Integrated National Energy and Climate Plan for the period 2021-2030’, European Commission, Nicosia, Cyprus, Nov. 2019.

Methodology for ESS ranking

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Mechanical storage	Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES), Flywheels
Lead-acid batteries	Valve-Regulated Lead Acid (VRLA)
High-temperature batteries	Sodium nickel chloride batteries (NaNiCl), Sodium sulphur batteries (NaS)
Flow batteries	Vanadium flow batteries, Zinc bromine hybrid flow batteries (ZnBr)
Lithium-ion batteries	Lithium Nickel Manganese Cobalt batteries (NMC), Lithium Nickel Cobalt Aluminium batteries (NCA), Lithium Ferro Phosphate batteries (LFP), Lithium Titanate Oxide batteries (LTO)

Technical

- Efficiency (AC-to-AC)
- C-rate minimum
- C-rate maximum
- Maximum depth of discharge
- Maximum operating temperature
- Safety (thermal stability)
- Energy density
- Power density

Commercial

- Storage CAPEX
- Power converter CAPEX
- Development and construction time
- Operating cost

Environmental

- Climate change - Human health
- Human toxicity
- Particulate matter
- Fossil resource
- Climate change - Ecosystems

Quantifiable energy storage services

Bulk Energy Services

- Renewable energy time-shift

Ancillary Services

- Fast frequency response
- Operating and replacement reserves
- Renewable smoothing
- Flexible ramping
- Reactive power management

Costumer Energy Services Management

- Power reliability
- Behind The Meter (BTM) power management

Suitability matrix for different applications

Methodology for ESS ranking

Suitability matrix for different applications												
	Lead-acid battery	Mechanical storage			Lithium-ion batteries				High-temperature batteries		Flow batteries	
Parameters	**VRLA**	**Pumped Hydro**	**CAES**	**Flywheels**	**NMC**	**NCA**	**LFP**	**LTO**	**NaS**	**NaNiCI2 (Zebra)**	**ZBB**	**VRB**
Renewable shifting	11	4	8	12	1	2	3	5	5	7	9	10
Renewable smoothing	6	7	9	5	1	3	2	4	7	9	11	12
Flex ramping	11	4	8	12	1	2	3	5	5	7	9	10
Ancillary services	6	7	9	5	1	3	2	4	7	9	11	12
Reactive power management	8	7	10	5	1	2	3	4	6	9	11	12
BTM power management	5	12	12	9	1	2	3	4	6	7	8	12

Methodology for Cost Benefit Analysis of grid level ESS

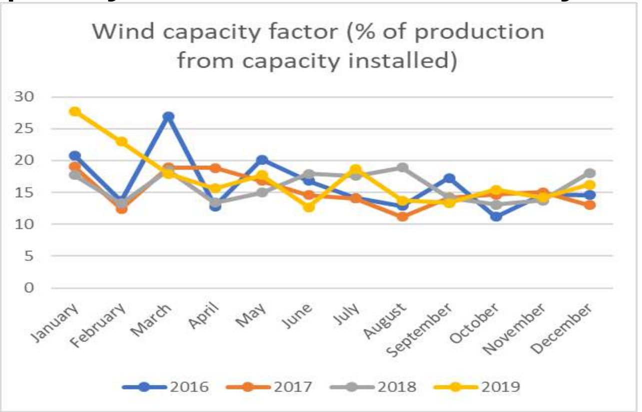
The goal of this economic analysis is to extract the range of parameter values enabling a positive outcome of the Cost-Benefit-Analysis (CBA).

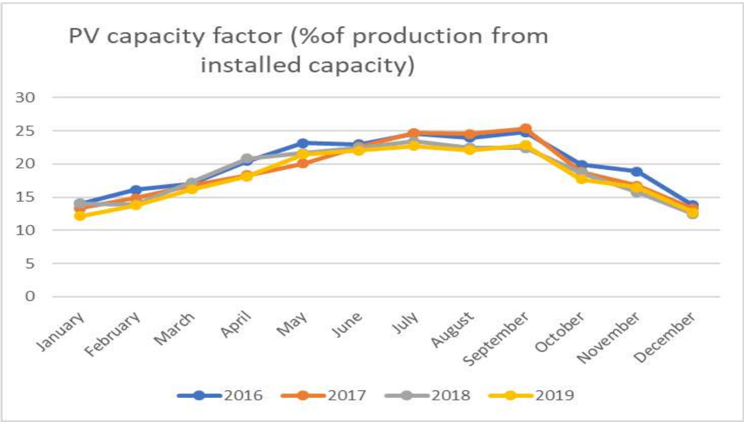
- **Net Present Value (NPV)**
  - NPV is used to assess the profitability of the investment
  - *NPV equals the present value of net cash inflows generated by a project minus the initial investment on the project*
- **Define Boundaries Conditions and Set Parameters**
  - **Discount Rate** (**4%** EC Delegated Regulation No 480/2014)
    - *considers the time value of money and the risk/uncertainty of anticipated future cash flows*
  - **Time horizon of the CBA** (10 years: 2020-2030, and ref. year 2018)
  - **Schedule of implementation** (100% of ESS is immediately available)
  - **Implemented technology** (Li-Ion BESS)
  - **Maturity of technologies and degradation of the system** (2% capacity reduction/year)
  - **Impact of the regulatory framework** (no penalty for RES curtailment, only upM ESS considered for complementing flexibility provision of all IPP)

Methodology for Cost Benefit Analysis of grid level ESS

Follows the highest standards and guidelines of the EnTSO-E for financing ESS for TSOs

- Run system models (UC/ED) for each year (relevant years) in the planning horizon (2020-2030) for the two study cases (no ESS and with ESS)
- The model considers that ESS would contribute to system reserve and ramping, besides overall cost reduction (increase RES integration ⬄ reduced RES curtailment)
  - NG availability (2022)
  - New CC units 2024
- Create time series of expected load demand and RES generation according to the expected installed capacity and their seasonality





Methodology for Cost Benefit Analysis

Calculation method for benefits and costs:

- Fuel savings due to integration of RES.
- Avoided CO2 emission costs.
- Variable & operating maintenance (V&OM) costs.
- RES integration cost savings due to avoidance cost variation

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Benefits											
B1. Socio-economic welfare (SEW in €)	840.083	1.295.995	3.123.702	3.441.668	3.758.624	4.161.529	3.608.628	4.047.479	4.119.293	4.236.513	4.557.540
B2. Additional societal benefit due to CO_2 variation (€)	2.615.732	2.700.130	730.050	794.754	859.458	908.900	796.085	824.661	910.384	996.108	1.081.831
B3. RES integration (MWh/year)	753,24	2.852,75	4.412,26	4.714,37	5.016,49	7.593,3	7.230,55	3.744,00	13.018,27	22.292,54	31.566,81
Costs						.					
C1. CAPEX (€)	(45.000.000)										
C2. OPEX (€)	(560.000)	(548.800)	(537.600)	(526.400)	(515.200)	(504.000)	(492.800)	(481.600)	(470.400)	(459.200)	(448.000)
Additional Benefit											
Salvage Value of ESS and CPS (€)											15.000.000
Free Cash Flows (€)	(42.104.185)	3.447.325	3.316.153	3.710.023	4.102.883	4.566.429	3.911.913	4.390.541	4.559.277	4.773.421	20.191.371
NPV											**2.454.266**

Methodology for Cost Benefit Analysis

Sensitivity analysis

% change in CAPEX	CAPEX (EUR/MWh)	NPV
-50%	225.000	24.954.266
-40%	270.000	20.454.266
-30%	315.000	15.954.266
-20%	360.000	11.454.266
-10%	405.000	6.954.266
0%	450.000	2.454.266
10%	495.000	(2.045.734)
20%	540.000	(6.545.734)
30%	585.000	(11.045.734)
40%	630.000	(15.545.734)
50%	675.000	(20.045.734)

Note: this CAPEX is for the entire system, including the CPS, while the salvage value of the system was kept constant

% change in OPEX	OPEX (EUR/MWh)	NPV
-50%	2.800	4.810.479
-40%	3.360	4.339.236
-30%	3.920	3.867.993
-20%	4.480	3.396.751
-10%	5.040	2.925.508
0%	5.600	2.454.266
10%	6.160	1.983.023
20%	6.720	1.511.781
30%	7.280	1.040.538
40%	7.840	569.295
50%	8.400	98.053

% change in Fuel Cost	NPV
-50%	(9.183.738)
-40%	(6.856.137)
-30%	(4.528.537)
-20%	(2.200.936)
-10%	126.665
0%	2.454.266
10%	4.781.867
20%	7.109.467
30%	9.437.068
40%	11.764.669
50%	14.092.270

% change in CO2 Allowance Cost	NPV
-50%	(616.644)
-40%	(2.462)
-30%	611.720
-20%	1.225.902
-10%	1.840.084
0%	2.454.266
10%	3.068.448
20%	3.682.630
30%	4.296.812
40%	4.910.994
50%	5.525.176

% change in Discount Factor	NPV
-50%	8.125.575
-40%	6.912.722
-30%	5.740.747
-20%	4.608.032
-10%	3.513.031
0%	2.454.266
10%	1.430.324
20%	439.854
30%	(518.436)
40%	(1.445.781)
50%	(2.343.366)

% change in Salvage Value	NPV
-50%	(2.712.807)
-40%	(1.679.392)
-30%	(645.978)
-20%	387.437
-10%	1.420.851
0%	2.454.266
10%	3.487.680
20%	4.521.095
30%	5.554.509
40%	6.587.924
50%	7.621.338

(in collaboration with Deloitte)

Methodology for CBA of BtM Storage

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The goal of this CBA is to apply the same principals of the NPV approach in the scenario that the *net-metering* scheme switches to *net-billing* for all prosumers (IRENA, 2015)

- **Network users at LV side of the DSO**
  - Pure consumer (no PV)
  - Prosumer in net-metering scheme (NM)
  - Prosumer in net-billing scheme (NB)
- **Variables impacting the costs and benefits**
  - Based on the tariffs of the EAC supply (reference year 2018)
  - CAPEX of BESS+CPS (tendering offers)

Battery configuration	Inverter Rating (kW)	Rated Capacity (kWh)	Usable Capacity (kWh)	Warranty	Rated Cycles	Cost (€) without VAT
Inverter: Fronius 5.0 Battery: LG Chem 10H (+accessories)	5	9.8	9.3	10	6000	7550
Inverter: Fronius 5.0 Battery: LG Chem 7H (+accessories)	5	7	6.6	10	6000	6550
Inverter: Solttaro 1Φ Battery: Solttaro (LiFe04)	5	5	4.5	Inverter: 5 Battery: 10	10000	2960

Name	Price
Variable charges	
Energy Charge per unit (kWh)	0.0923 € / kWh
Network Charge per unit (kWh)	0.0321 € / kWh
Ancillary Services Charge per unit (kWh)	0.0067 € / kWh
Fuel Adjustment charge per unit (kWh)	0.0162 € / kWh (January to June) 0.0431 € / kWh (July to December)
RES and ES Funds per unit (kWh)	0.0100 € / kWh
Fixed charges	
Producer's fee	4.828 € / kW
Producer's PSO	0.191 € / kW
Producer's RES and ES funds	2.683 € / kW
Constant charges	
Meter Reading Charge	0.98 €
Energy Supply Charge	4.68 €
Energy purchase from RES	
Purchase Price per unit (kWh)	0.1042 € / kWh

Methodology for CBA of BTM Storage

- **Classification of the prosumer based on ratio between PV capacity and load**

	Low consumption Low production	Low consumption High production	High consumption Low production	High consumption High production
Consumption (kWh)	4405	5334	8807	9550
Production (kWh)	4056	5408	4281	5512

- **Scenarios in the Sensitivity Analysis**

Increasing of RES penetration and fuel price for the years from 2020 to 2030

Year	Increasing of RES Penetration (%)	Increasing of Gas Oil Price (%)	Increasing of Natural Gas Price (%)
2020	0	0	0
2021	0	0	0
2022	25.95	4.82	0
2023	4.52	6.30	4.88
2024	8.65	5.19	4.37
2025	3.10	4.17	3.81
2026	2.15	2.49	1.59
2027	1.26	2.21	1.46
2028	0	1.47	1.59
2029	14.52	2.26	1.58
2030	9.78	1.35	2.25

User	NPV for Net-Metering scheme (€)		NPV for Net-Billing scheme							
			Without installed Battery (€)	with installed Battery in 2020 (€)			with installed Battery in 2022 (€)			
				Usable Capacity of Battery						
	Case 1	Case 2		4.5 kWh	6.6 kWh	9.3 kWh	4.5 kWh	6.6 kWh	9.3 kWh	
Low Consumption Low Production	6021	7576	5874	3253	-828	-1914	3721	332	-569	
Low Consumption High Production	8032	9596	7943	5331	1289	228	5312	2442	1564	
High Consumption Low Production	6321	7806	6666	3855	-278	-1378	4772	914	1	
High Consumption High Production	8576	10021	8670	6023	1984	967	6494	3140	2299	

Case1: the charges are fixed
Case2: the charges are variable and depend on the volume of imported energy

Conclusions

- Integrated framework for storage valuation for the PS of Cyprus based on IRENA's and EnTSO-e's guidelines
- Ranking Methodology based on Commercial, Technical and Environmental parameters of market available ESS and their suitability to provide stacking of services for power system applications
  - Li-Ion technology the most promising for both grid and BTM
  - Pumped-hydro despite being cost-effective is environmental prohibitive in Cyprus
- Both BTM and Grid ESS might provide profit, assuming the current electricity market regulation
- Their profitability was assessed also based on sensitivity parameters such as fuel, CO_2, discount rate, etc.

Conclusions

- Distributed LV storage might provide direct benefit to prosumers, while mitigating many DSO's operational challenges
- BTM hybrid RES-ESS at grid level needs a separate analysis (the UC/ED model was designed for UpM option)
- Limitation of the study by ignoring the role of the interconnector (impact only for the CBA of ESS at grid level)


Thank You!