Meeting Cyprus' future electrical energy demand in a cost optimal way, under various RES penetration scenarios

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SUSTAINABLE ENERGY CONSULTING & DEVELOPMENT

Contents

- Electrical energy storage benefits
- The Dispa-SET model
- Simulation input
- Main assumptions
- Simulation results
  - Isolated grid case
  - Interconnector case

Potential benefits of electrical energy storage

User
- ✓Increase power quality
- ✓Lower contract capacity
- ✓Demand charge management

Generation
- ✓Decrease power reserve
- ✓Defer new power plants erection

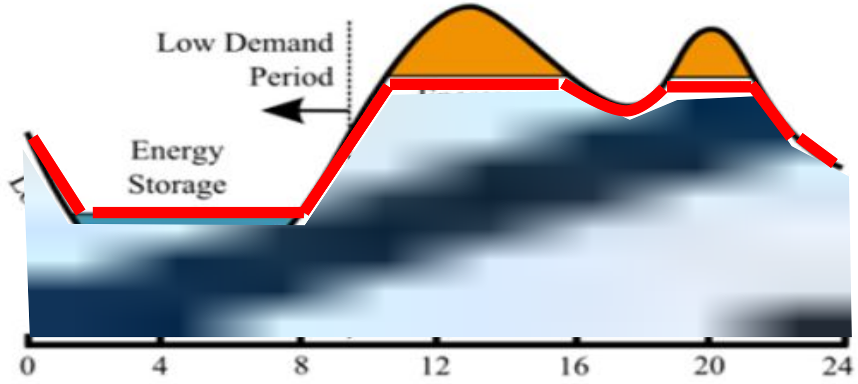
Transmission/Distribution
- ✓Connection energy management
- ✓Transmission congestion relief
- ✓Transmission upgrade deferral

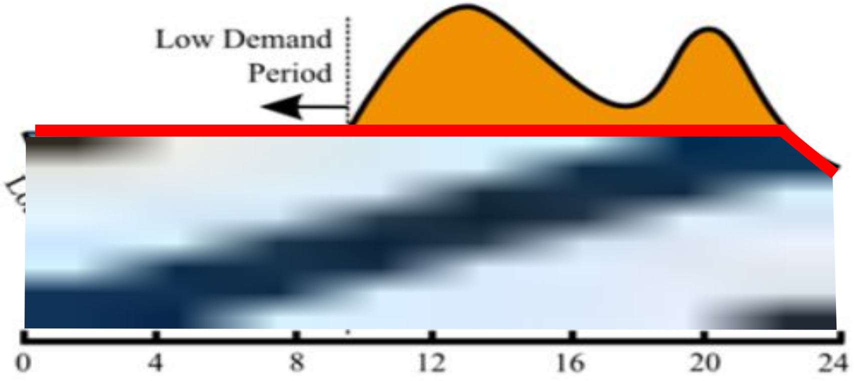
Dispatch
- ✓Energy management
- ✓Peak shaving/Load leveling
- ✓Generator optimal dispatching

Environmental
- ✓Further RES penetration
- ✓Suppressing emissions
- ✓Environmental policy support

Storage for scheduling generation

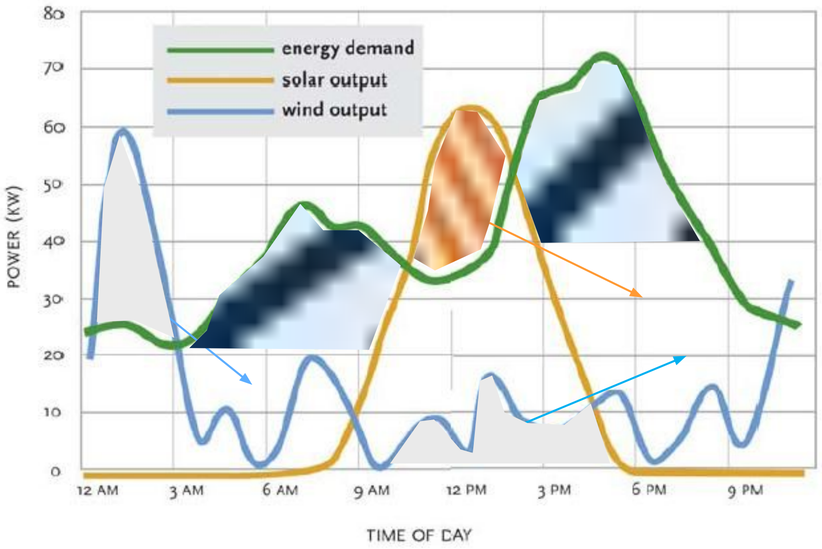
Low RES share





- Demand profile alteration
- Conventional generators dispatch scheduling

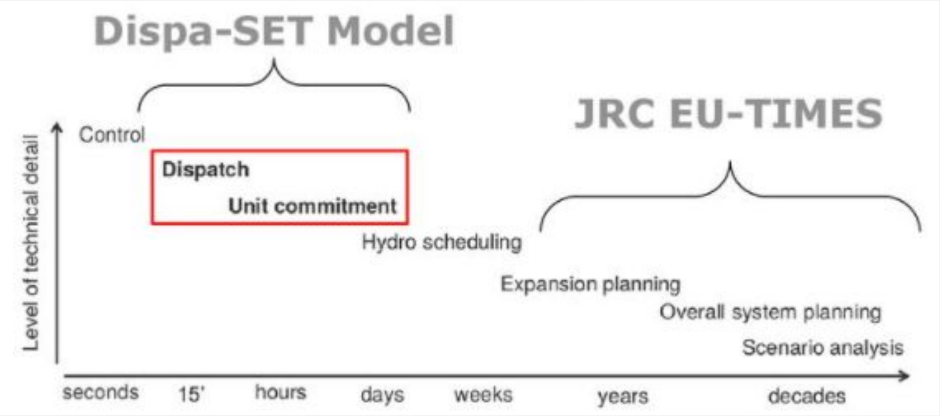
High RES share

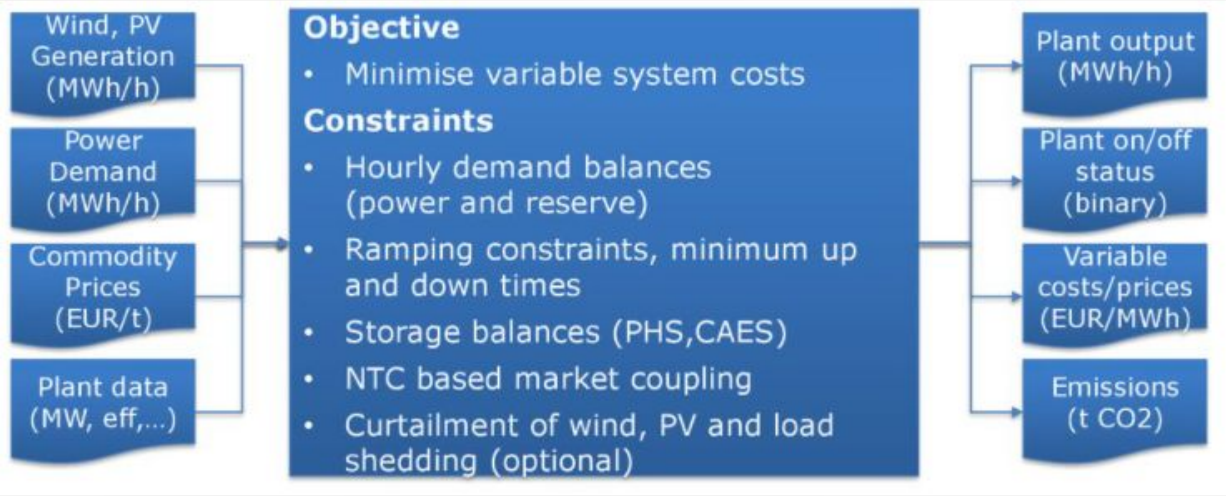


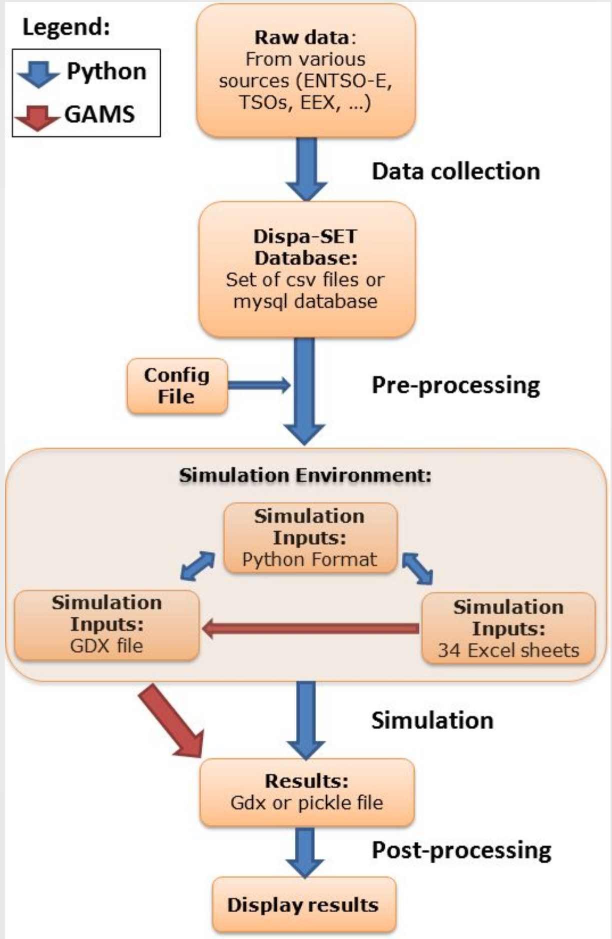
- Avoid RES curtailment
- Conventional generators dispatch scheduling
- Facilitate further DSM techniques (valley filling, load growth, etc.)
- **Accommodate further RES penetration to achieve climate change goals**

JRC's Model : Dispa-SET

Dispa-SET : Unit commitment and dispatch model for the optimization of short-term scheduling of power stations, providing insight on power system adequacy and flexibility needs to accommodate growing share of Renewable generation







Dispa-SET application

- **Dispa-SET for the EU28**

Sylvain Quoilin (University of Liège, KU Leuven)
Konstantinos Kavvadias (European Commission, Institute for Energy and Transport)
Matija Pavičević (KU Leuven)

- **Dispa-SET for the Balkans region**

Matija Pavičević (KU Leuven)
Sylvain Quoilin (University of Liège, KU Leuven)
Andreas Zucker (Joint Research Centre, European Commission)

- **Dispa-SET for the Belarus**

Matija Pavičević (KU Leuven)
Darya Muslina (Belarusian National Technical University)
Yuliya Stanetskaya (Belarusian National Technical University)

- **Dispa-SET for Belgium**

Coupling a power system model to a building model to evaluate the flexibility potential of DSM at country level

- **Dispa-SET for Bolivia**

Techno-economic assessment of hinge renewable energy source penetration in the Bolivian interconnected electric system

- **Dispa-SET for the Netherlands**

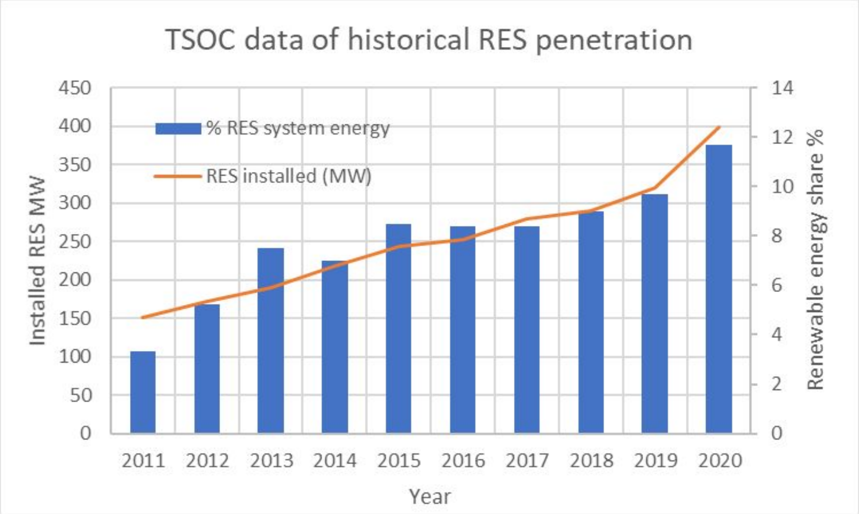
Evaluating the impact of EV charging demand on the Dutch energy system

- **Dispa-SET for Central Europe**

Evaluating flexibility and adequacy in future EU power systems: model coupling and long-term forecasting

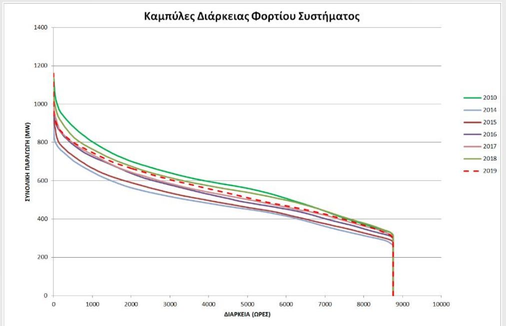
Dispa-SET application to Cyprus' grid

- Based on National Energy and Climate Plan (NECP) 26% RES penetration goal in electricity by 2030 (or the more recent of 30%) has been checked.



- Future RES penetration scenarios have been simulated, with and without storage:
  - Battery storage systems (BATS),
  - Pumped Hydro (HPHS) and
  - Hydrogen (HYDR)
- Cyprus' grid is either considered isolated or interconnected to Greece/Israel by the year 2030.

Simulation input



Base Scenario

- 2019 demand and generation data from TSOC (data transformed at 1h interval from 15minute interval)
- No outage data available for generators
- RES generators installations considered constant in power throughout the year

Future Scenarios

- For Scenarios of 2030 and 2040 the hourly load profile of 2019 has been used, while the total annual generation/demand for 2030 is estimated at 7,52GWh and for 2040 8,64GWh
- As a base for RES installations, new CCGT and conventional installations power, for future scenarios the PPM scenario of the NECP has been used (without the EuroAsia Interconnector)

(in MW)	**2020**	**2021**	**2025**	**2030**	**2035**	**2040**
New CCGT[25]	0	216	432	432	432	648
Solar PV	360	380	460	804	1.653	1.892
Solar Thermal	0	0	50	50	50	500
Wind	158	158	198	198	198	198
Biomass & waste	17	22	42	58	58	58
Pumped Hydro	0	0	0	0	130	130
Li-Ion Batteries	0	0	0	0	211	655

- The PPM scenario above is the result of a previous analysis. Since it has been used as a base, no optimization has been done on the future power installations for 2030 and 2040. Though, variations of the PPM scenario have been set (with storage and more RES) for research purposes.
- Variations of the fuel prices for the conventional generators have been considered, while no operational cost has been set for RES installations. Startup and no-load costs have been taken into account for conventional generators, while ramping costs have been considered for biomass.

Assumptions

The main assumptions made while setting up the Dispa-SET simulation set are the following:

- Isolated system with no interconnections
- No transmission losses considered
- No outage factors for the conventional generators (no pertinent data retrieved)
- Only one "OIL" fuel considered (Dispa-SET has only one OIL as input)-
- Fuel prices considered constant throughout the year (even though Dispa-SET can be fed with hourly profiles)
- CO2 cost per tonne equivalent is set the same at 25€/tCO_2 for all simulation cases
- No variable (fuel) cost associated with renewables (Wind, PV, Solar Thermal – ST)
- Clustering of units allowed – Not interested in particular generator production
- Dispatch of generators to satisfy demand with a horizon of 3 days and 1 day look ahead
- Simulations duration for year y: Start at 00:00 hours/day1 - End at 23:00 hours/day 365
- No installation, depreciation or O&M costs have been considered

Scenarios simulated

The following scenarios have been investigated by employing Dispa-SET tool, aiming to optimize the system's operation.

Table 3.3: Fuel price variation scenarios

Basic Scenario	Oil price	Gas price	Scenario variation 1	Scenario variation 2
Scen1	Low – 32,5€/boe	-	-	-
Scen2	Low – 32,5€/boe	High – 50€/boe	Scen2p1 Oil 49 €/boe Gas 24,5€/boe	Scen2p2 Oil 40€/boe Gas 40€/boe
Scen2.1	Low – 32,5€/boe	High – 50€/boe	Scen2.1p1 Oil 49 €/boe Gas 24,5€/boe	Scen2.1p2 Oil 40€/boe Gas 40€/boe
Scen3	Low – 32,5€/boe	High – 50€/boe	Scen3p1 Oil 49 €/boe Gas 24,5€/boe	Scen3p2 Oil 40€/boe Gas 40€/boe
Scen3.1	Low – 32,5€/boe	High – 50€/boe	Scen3.1p1 Oil 49 €/boe Gas 24,5€/boe	Scen3.1p2 Oil 40€/boe Gas 40€/boe

	GENERATORS						STORAGE		
	Conventional	Wind	PV	Biomass	Solar Thermal	New CCGT	HPHS	BATS	HYDROGEN
	MW	MW	MW	MW	MW	MW	MW	MW	MW
...st effective system operation for year 2019 – **Scen1**	1473,15	157,5	135,78	12,1	0	0	0	0	0
...st effective system operation for year 2030 - **Scen2**	1113,15	198	804	58	50	432	0	0	0
Cost effective system operation for year 2030 with 3 Storage technologies – **Scen2.1**	1113,15	198	804	58	50	432	130	41	20
Cost effective system operation for year 2030 with Li-ion Battery Storage – **Scen2.2**	1113,15	198	804	58	50	432	0	171	0
Cost effective system operation for year 2030 with Pump Hydro Systems (HPHS) – **Scen2.3**	1113,15	198	804	58	50	432	171	0	0
Cost effective system operation for year 2030 with Hydrogen Storage – **Scen2.4**	1113,15	198	804	58	50	432	0	0	171
Cost effective system operation for year 2040 as in Table 3.2 – **Scen3**	1113,15	198	1892	58	50	648	130	655	100
Cost effective system operation for year 2040 without any storage Systems– **Scen3.1**	1113,15	198	1892	58	50	648	0	0	0
Cost effective system operation for year 2030 with additional PV and storage – **Scen2.1s1**	1113,15	198	1045,2	58	50	432	169	53,3	26
Cost effective system operation for year 2030 with additional PV and storage – **Scen2.1s2**	1113,15	198	1125,6	58	50	432	182	57,4	28

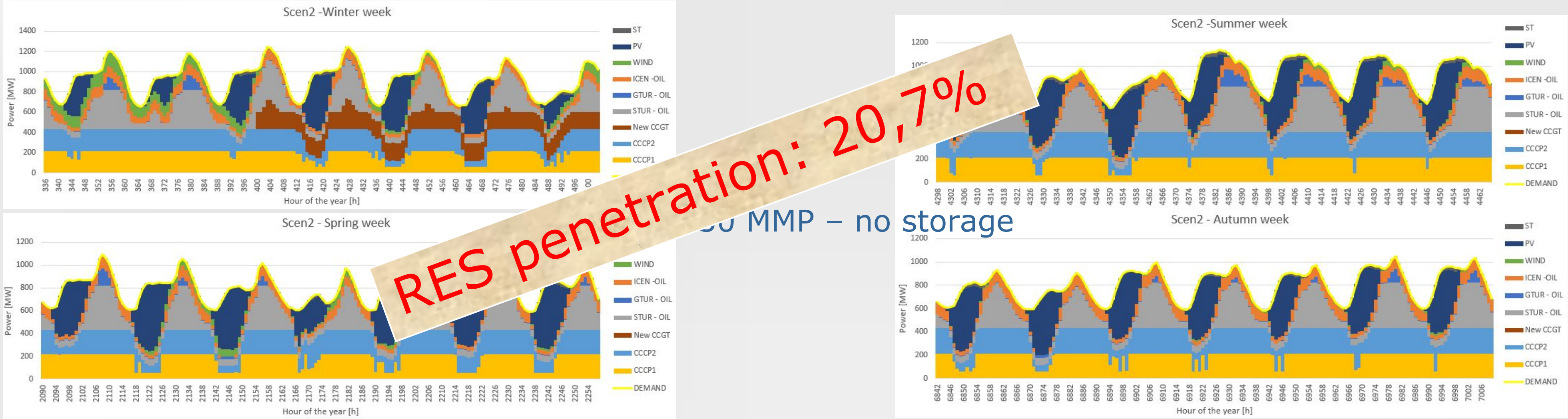
PPM

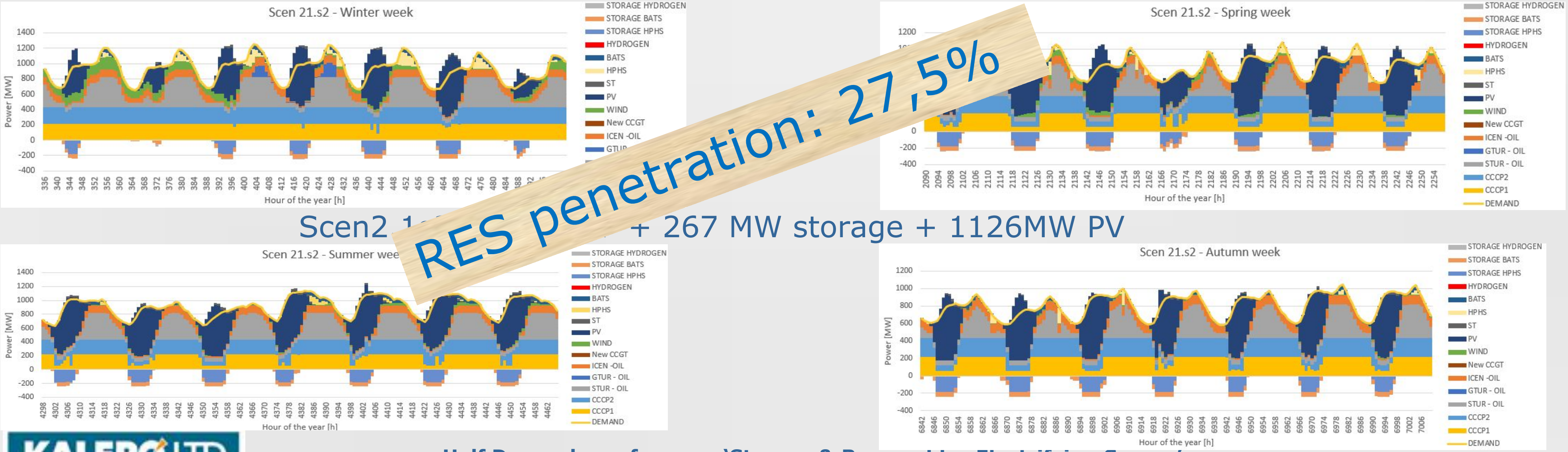
PPM

+30% PV + storage

+40% PV + more storage

Scenario profiles (indicative)





Scen2 … + 267 MW storage + 1126MW PV

Simulation results

SIMULATION SCENARIOS	System Cost [€]	Energy supplied to the grid [MWh]	Demand [MWh]	Unit Cost [€/MWh]	RES Energy [MWh]	Curtailed Energy [MWh]	RES/ electr. Consumption [%]	Energy from storage [MWh]			
								HPHS	BATS	H2	TOTAL
Scen1	294184032.7	5119511.3	5119863.6	57.5	501101.7	37.1	9.8				
Scen2	388286532.0	7514563.7	7515882.8	51.7	1559433.3	7279.8	20.7				
Scen2p1	358598036.5	7515733.806	7515882.8	47.7	1561946.212	5530.6863	20.7				
Scen2p2	394792709.6	7515701.355	7515882.8	52.5	1548913.577	54786.117	19.9				
Scen2.1	385052262.0	7626307.5	7515882.8	51.2	1569337.7	30.6	20.9	41696.6	42880.1	48.0	84624.7
Scen2.1p1	343382789.2	7851239.788	7515882.8	45.7	1569380.158	39393	20.4	172498.7	80483.61	198.511	253180.8
Scen2.1p2	387720403	7671443.194	7515882.8	51.6	1568539.281	39701.899	20.3	54186.62	64613.3	269.082	119069.0
Scen2.2	384912823.5	7634772.3	7515882.8	51.2	1569319.6	24.3	20.9		94402.6		94402.6
Scen2.3	385305610.3	7615111.1	7515882.8	51.3	1569295.2	13.3	20.9	73403.4			73403.4
Scen2.4	386449327.8	7532487.5	7515882.8	51.4	1569302.8	17.2	20.9			5676.4	5676.4
Scen3	362746203.4	9386920.6	8643265.2	42.0	3268588.8	8572.0	37.7	136587.7	416402.2	11329.9	564319.8
Scen3p1	409377780.3	9514049.205	8643265.2	47.4	3225359.268	45314.04	36.8	183807.8	427213.6	27971.6	638993.0
Scen3p2	354382631.2	9529804.326	8643265.2	41.0	3209386.674	60082.991	36.4	188723.7	432744.8	28717.2	650185.7
Scen3.1	414221854.6	8633341.0	8643265.2	47.9	2820996.8	166197.6	30.7				
Scen3.1p1	344917103.6	8642856.188	8643265.2	39.9	2382525.955	856114.3	17.7				
Scen3.1p2	410364779.9	8642582.583	8643265.2	47.5	2494197.504	745506.2	20.2				
Scen2.1s1	361781717.1	7684891.461	7515882.8	48.1	1947291.341	729.4	25.9	64230.31	63943.22	207.259	128380.8
Scen2.1s2	354423462.3	7719066.253	7515882.8	47.2	2071368.639	2302.2	27.5	75723.29	77158.73	836.345	153718.4
Scen2.1s2p1	312692823.8	8080532.591	7515882.8	41.6	2072535.886	1495.883	27.6	296773.7	126419.6	1370.58	424563.9
Scen2.1s2p2	358240198.6	7846980.646	7515882.8	47.7	2066592.672	4760.3274	27.4	141263.7	107019.8	1745.58	250029.1

Scen2.1s2 achieves the initial 26% RES penetration (27,5%) in 2030 goal, but not the current one

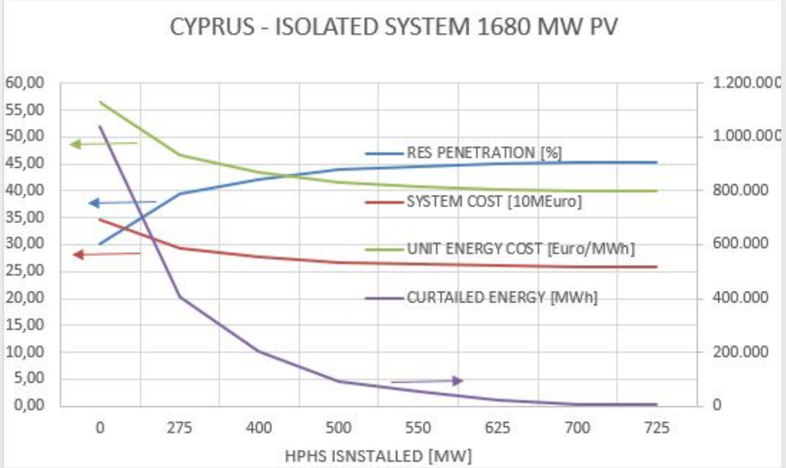
Scen3 achieves 37,7% RES penetration in 2040, employing +100MW storage from PPM scenario

RES penetration – Isolated grid

a) Maximize RES penetration - 1680 MW PV will be installed (PPM scenario for 2035)
b) Cyprus grid will remain isolated
c) 0 MW to 725MW of Pump Hydro Systems (HPHS) installed (8h nominal capacity)
d) A total annual demand of 6120 GWh for 2030
e) Capacity distribution for the generators

GENERATORS TECHNOLOGY	MODEL CLUSTER	INSTALLED CAPACITY [MW]
PV	[4] - CY_PHOT_SUN	1680
SOLAR THERMAL	[7] - CY_STUR_SUN	50
WIND	[3] - CY_WTON_WIN	198
GAS TURBINE (OIL)	[0] - CY_GTUR_OIL	128
INT. COMB. ENGINE (OIL)	[1] - CY_ICEN_OIL	102
COMB. CYCLE (OIL)	[2] - CY_COMC_OIL	836
BIOMASS	[5] - CY_STUR_BIO	58
COMB. CYCLE (GAS)	[6] - CY_COMC_GAS	432

INSTALLED HPHS CAPACITY [MW]	RES PENETRATION [%]	CURTAILED ENERGY [MWh]	UNIT ENERGY COST [Euro/MWh]
0	30,02	1.037.626	56,49
275	39,38	405.551	46,63
400	42,22	202.272	43,36
500	43,86	92.120	41,50
550	44,43	56.263	40,86
625	44,99	23.924	40,27
700	45,26	8.180	39,97
725	45,31	5.462	39,91



RES penetration – Interconnected grid

NEC plan (Greece)
Israeli Ministry of Energy

a) Interconnected grid between Greece-Cyprus-Israel of 2GW capacity by 2030
b) 2030 annual demand of 6,12 TWh for Cyprus, 95 TWh for Israel and 62 TWh for Greece
c) Capacity distribution for the generators as follows and two scenarios of (1) 750MW PV and (2) 1680MW PV installed in Cyprus.
d) Varying HPHS capacity from 0 to 700 MW and FUEL COSTS CONSIDERED THE SAME for all countries

SCENARIO 1 PV INSTALLED IN CYP

COUNTRY	GENERATORS TECHN	INSTALLED CAPACITY [MW]
CYPRUS	BATTERIES	41
	GAS TURBINES (OIL)	128
	SOLAR THERMAL	50
	COMBINED CYCLE (G	432
	BIOMASS	50
	PV	1680
	WIND	198
	COMBINED CYCLE (O	836
	INTERNAL COMB. EN	102
GREECE	BATTERIES	1300
	SOLAR THERMAL	100
	BIOMASS	300
	WIND	7050
	HYDRO	3900
	PV	7660
	STEAM TURBINE (GA	614
	INTERNAL COMB. EN	117
	GAS TURBINES (GAS)	1138
	COMBINED CYCLE (G	5041
ISRAEL	BATTERIES	3000
	BIOMASS	28
	HYDRO	7
	WIND	27
	SOLAR THERMAL	700
	PV	15000
	STEAM TURBINE (GA	3538
	COMBINED CYCLE (G	8740
	GAS TURBINES (GAS) [2] - IL_GTUR_GAS 592	592

SCENARIO 1 RESULTS

VARIATION	INSTALLED HPHS CAPACITY [MW]	CY RES PENETRATION [%]	CY CURTAILED ENERGY [MWh]	UNIT ENERGY COST [Euro/MWh]	NET TRANSFER FROM CY [MWh]
TRANSMISSION COST 5 Euro/MWh	0	1,34	0	49,44	-709997,6
	275	24,61	0	49,08	-950676,4
	400	24,21	0	52,12	-1063130,6
	700	23,24	0	51,86	-1233681,5
TRANSMISSION COST 30 Euro/MWh	0	1,29	0	50,93	451523,6
	275	19,92	0	49,91	497567,8
	400	19,55	0	49,81	504396,7
	700	18,95	0	49,67	487970,2

SCENARIO 2 RESULTS

VARIATION	INSTALLED HPHS CAPACITY [MW]	CY RES PENETRATION [%]	CY CURTAILED ENERGY [MWh]	UNIT ENERGY COST [Euro/MWh]	NET TRANSFER FROM CY [MWh]
TRANSMISSION COST 5 Euro/MWh	0	1,31	14855,15	49,04	653865,5
	275	39,14	1738,22	48,62	366348,5
	400	38,49	264,37	48,32	239038,5
	700	37,11	0,00	48,08	31292,2
TRANSMISSION COST 30 Euro/MWh	0	1,27	16735,32	49,82	1403662,6
	275	35,10	3750,86	49,22	1067688,4
	400	34,28	305,39	49,08	1034403,8
	700	32,92	16,02	48,85	989428,4

Cyprus is a net importer

Cyprus does not meat RES penetration goals

Isolated vs. Interconnected grid

INSTALLED HPHS CAPACITY [MW]	RES PENETRATION [%]	CURTAILED ENERGY [MWh]	UNIT ENERGY COST [Euro/MWh]
0	30,02	1.037.626	56,49
275	39,38	405.551	46,63
400	42,22	202.272	43,36
700	45,26	8.180	39,97

Isolated grid

Increasing storage capacity increases RES penetration and decreases energy cost

SCENARIO 2 RESULTS						
	VARIATION	INSTALLED HPHS CAPACITY [MW]	CY RES PENETRATION [%]	CY CURTAILED ENERGY [MWh]	UNIT ENERGY COST [Euro/MWh]	NET TRANSFER FROM CY [MWh]
	TRANSMISSION COST 5 Euro/MWh	0	1,31	14855,15	49,04	653865,5
		275	39,14	1738,22	48,62	366348,5
		400	38,49	264,37	48,32	239038,5
		700	37,11	0,00	48,08	31292,2
	TRANSMISSION COST 30 Euro/MWh	0	1,27	16735,32	49,82	1403662,6
		275	35,10	3750,86	49,22	1067688,4
		400	34,28	305,39	49,08	1034403,8
		700	32,92	16,02	48,85	989428,4

Interconnected grid

Increasing storage capacity decreases RES penetration, decreases net exports and decreases energy cost marginally

Questions ?

Thank you very much for your attention