Intelligent Energy Europe

Impact of Energy Storage in Autonomous Power Systems -Solutions for Greek Islands and Island of Mljet –Part of D.2.1 Deliverable

NTUA

Dr Antonis G. Tsikalakis
National Technical University of Athens
School of Electrical and computers Engineering

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Autonomous Power Systems APS-Special issues

- Large frequency deviations with relatively small production or demand changes.
- Low ratio of minimum/maximum demand.
- Technical limits of the installed thermal units
- Needs for meeting reactive power demand.
- Uncertainty to the operators due to changes in the intermittent resources production
- Therefore,sometimes RES production is curtailed in order to avoid technical violations up to 60% for Kythnos and up to 6% for Crete

For such issues or grid reinforcement energy storage can help

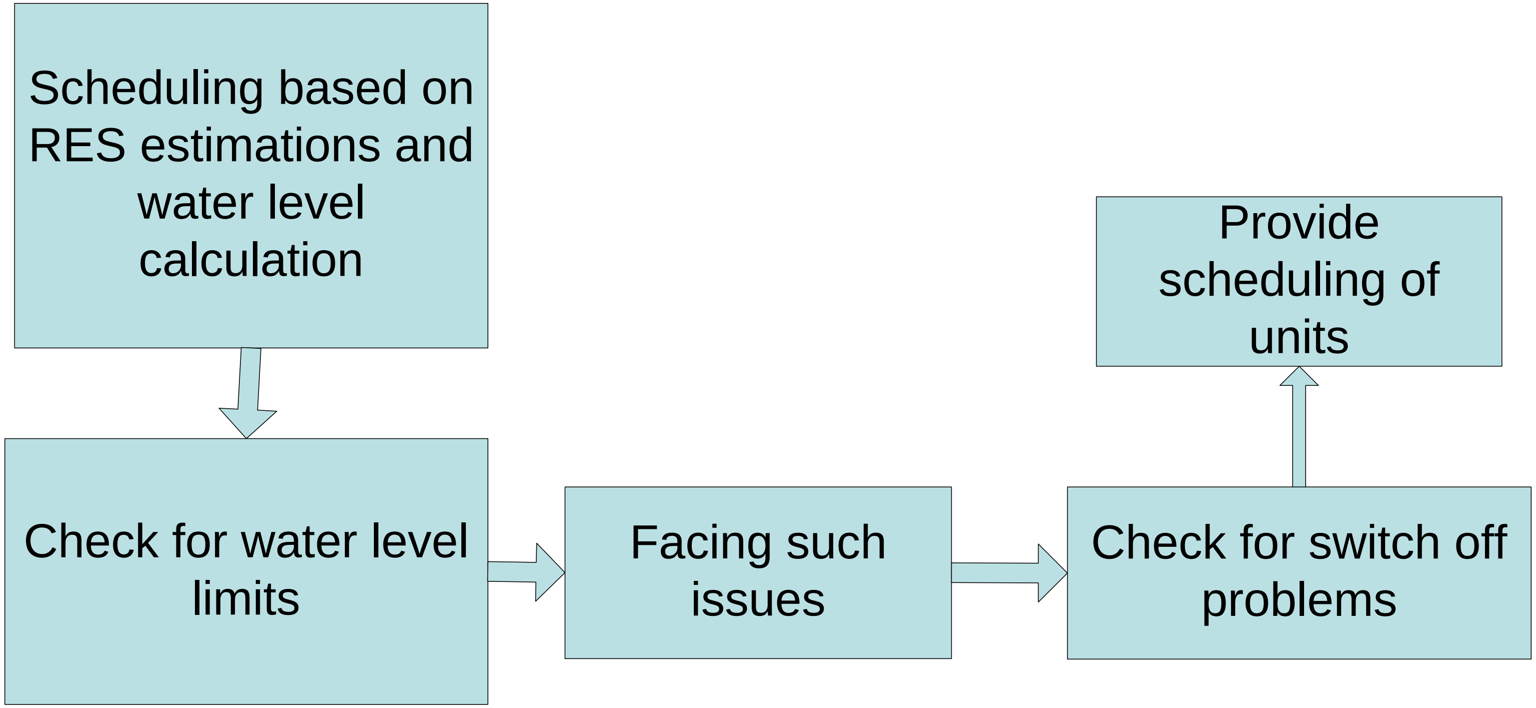
Mljet Case study

- Favourable wind+solar conditions.(1353kWh/KWp PV, 30.2%CF Wind)
- Weakly Interconnected island with Croatia mainland
- 3 Desalination plants already exist on the island
- Major consumption –Hotel Odisej also consumes significant amount of water transported to it, 100m^3/day
- Restrictions regarding wind turbine installations height. Small wind turbines chosen mainly for the eastern part.

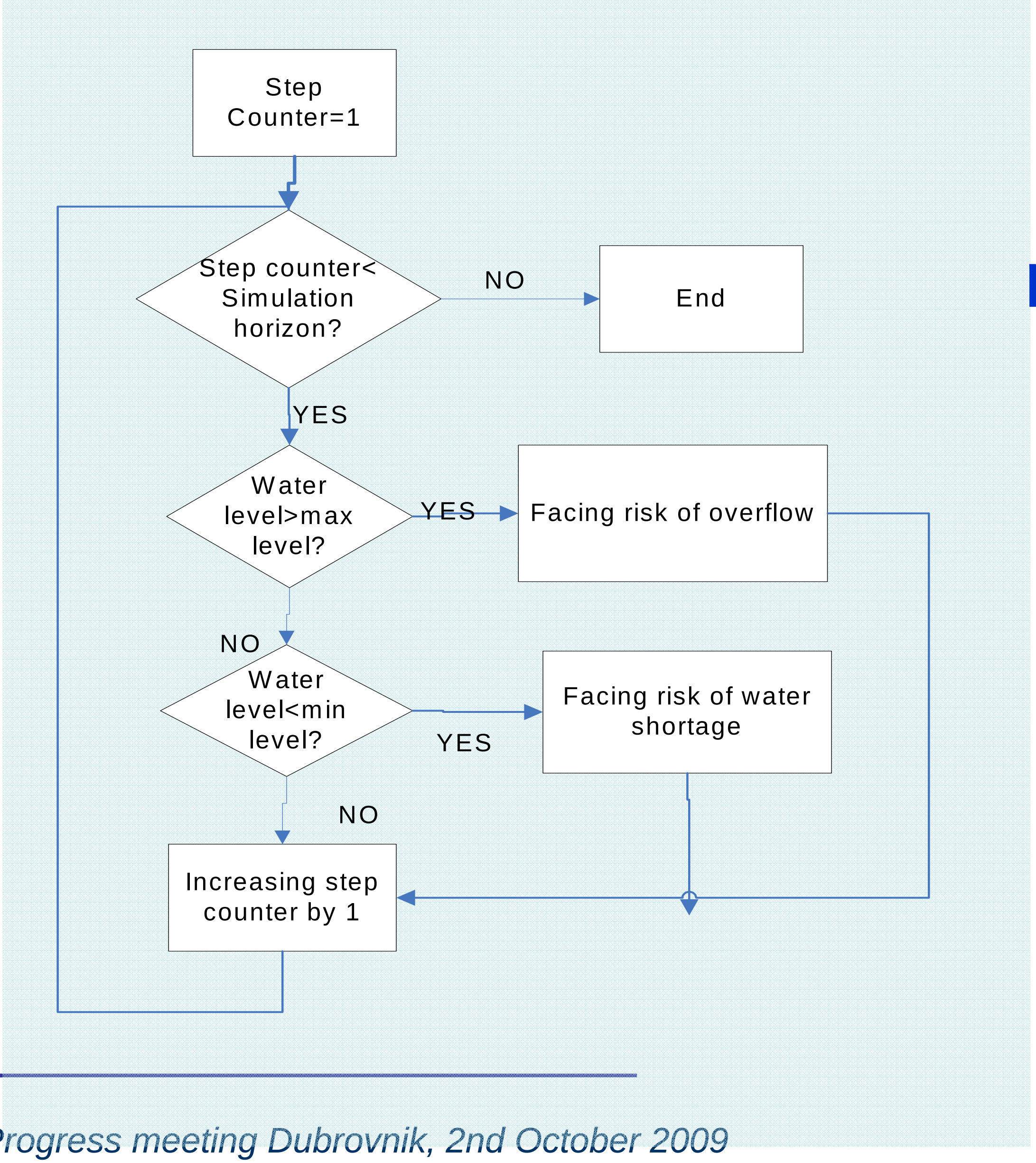
Why Desalination Loads ?

- Can Produce a valuable, especially for islands, commodity-potable water that can be safely stored instead of transported by tanker ships and requires significant amount of electricity
- The idea is to alter the time this energy is required when it is more convenient for the power system.
- These loads can :
  - Improve low/maximum ratio
  - Use RES whenever possible especially during periods when this energy might be curtailed
  - Can easier than other loads, due to few sites, be given order by island operators to increase/decrease production.
  - Can help reduce the uncertainty for that part of the load.

Simulation of operation of combined wind & Desalination plant



Facing water level constraints



Aiming at minimizing impact on power systems

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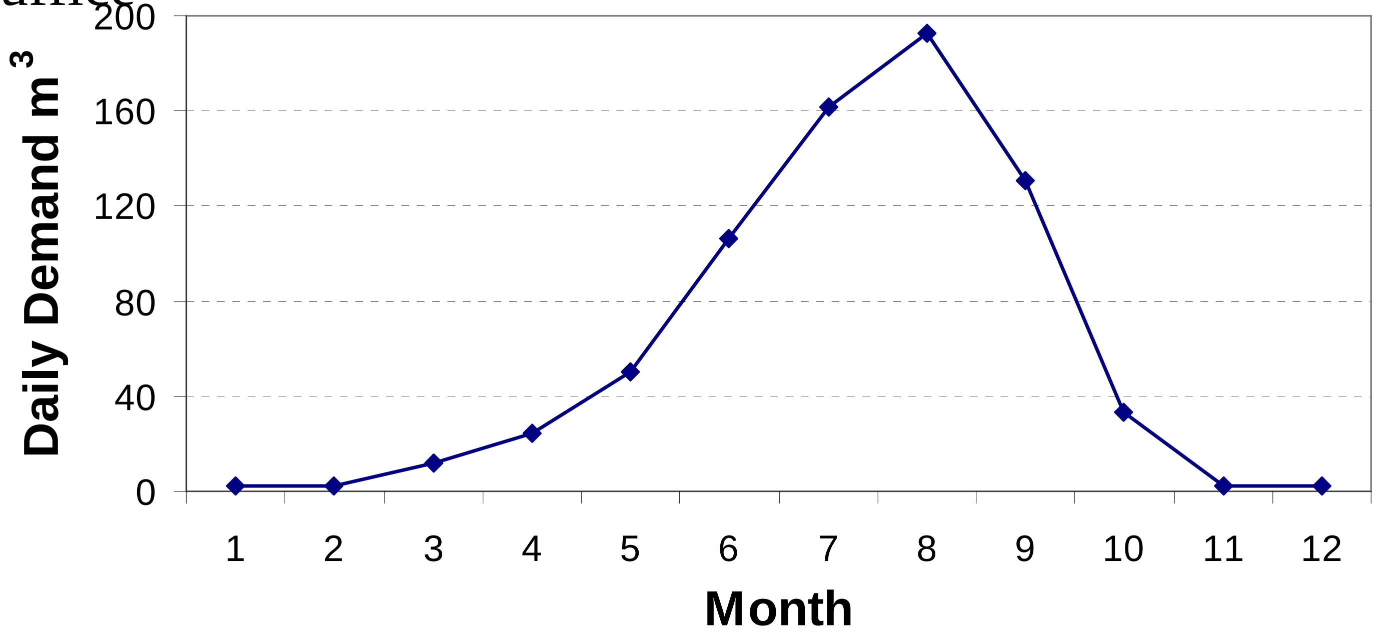
Mljet-Desalination Plants

Scenario 1: No co-operation simply addition of RES to meet existing Desalination plants electricity needs

Scenario 2: Meet the following water demand of Hotel Odissej via desalination. Water tank 577m^3 (3 August days)- Without RES 250m^3 would suffice



Mljet -Scenarios Simulated with Desalination Plant

1)For the 3 existing desalination plants, RES meeting their own needs are added

a) 1 W/T of 33kW (due to height restrictions)

b) PV (***Blato*** 44.9kW, ***Sobra*** 40.8kW ***Kozarica*** 9.42kW)-optimized in installation angles

2) For the major water and energy consumer,Hotel Odissej is studied

a) Addition of a Desalination plant only (3 units 19kW each-4.32m^3/h)

b) Addition of Wind power (35.6kW) w/o co-operation with the desalination plant

c) Addition of Wind power with co-operation with the desalination plant

d) Addition of PV (73.9kW optimized angles) w/o co-operation with the desalination plant

e) Addition of PV with co-operation with the desalination plant

- Sizing of Wind/PV via Homer Software

Mljet-Scenario 1 : Impact on Balance

	Wind	PV
Installed capacity (kW)	99	95
RES Production (MWh)	262.07	128.52
RES penetration (%)	5.95 (13.15% on eastern part)	2.92 (2.7% on eastern part)
Losses reduction (MWh)	6.66 (7.53%)	3.3 (3.72%)
CO_2 Avoided (tn)	200.8	99.6
Value for Croatian TSO (€)	11824.1	5800.08

Wind power for similar capacity- larger impact than PV

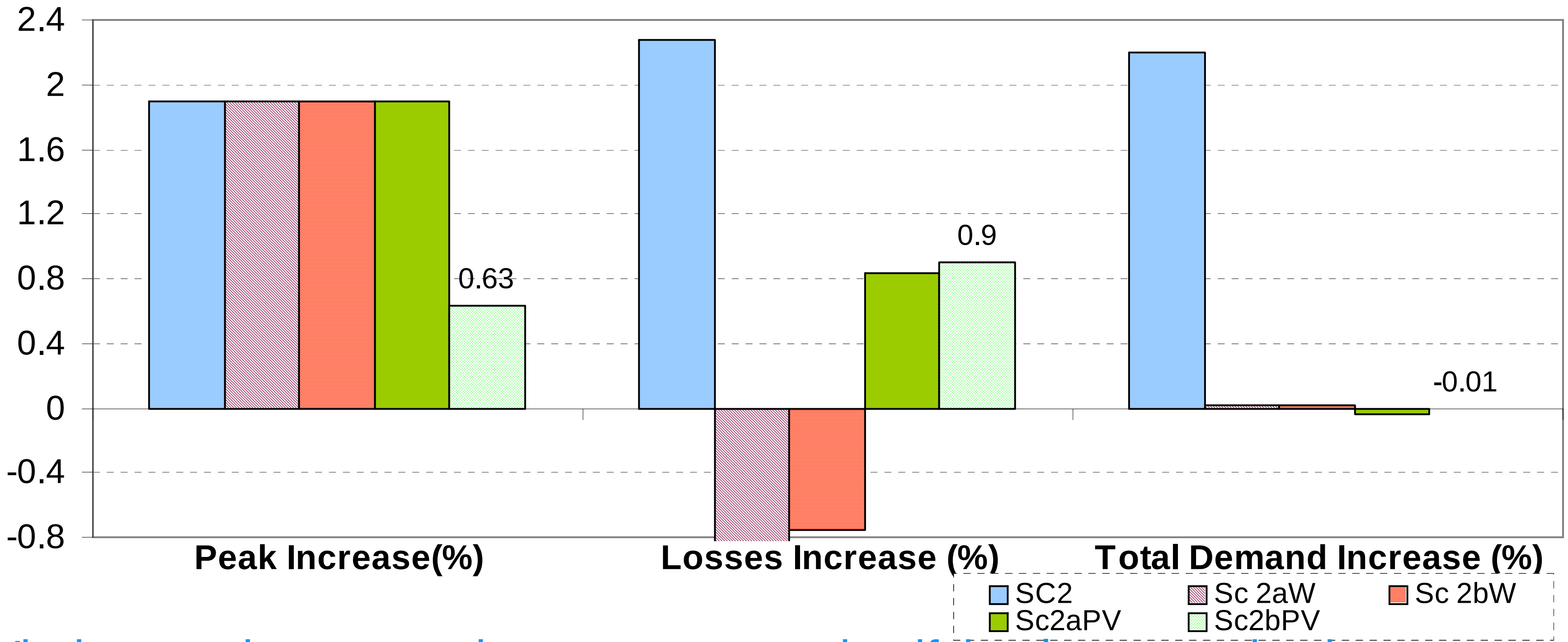
Mljet-Scenario 2 : Wind power installation

	Without co-operation	With co-operation
Negative Values (Buying from network)	36.4%	31.9%
Zero balance	13.7%	16.6%
Positive Value (Selling to the grid)	49.9%	51.5%
Confidence interval 95%, [2.5%, 97.5%]	[-37.9,34.2]	[-36.32,33.68]
Frequency within [-20kW, 20kW]	72.9%	80.53%

Mljet-Scenario 2 : PV installation

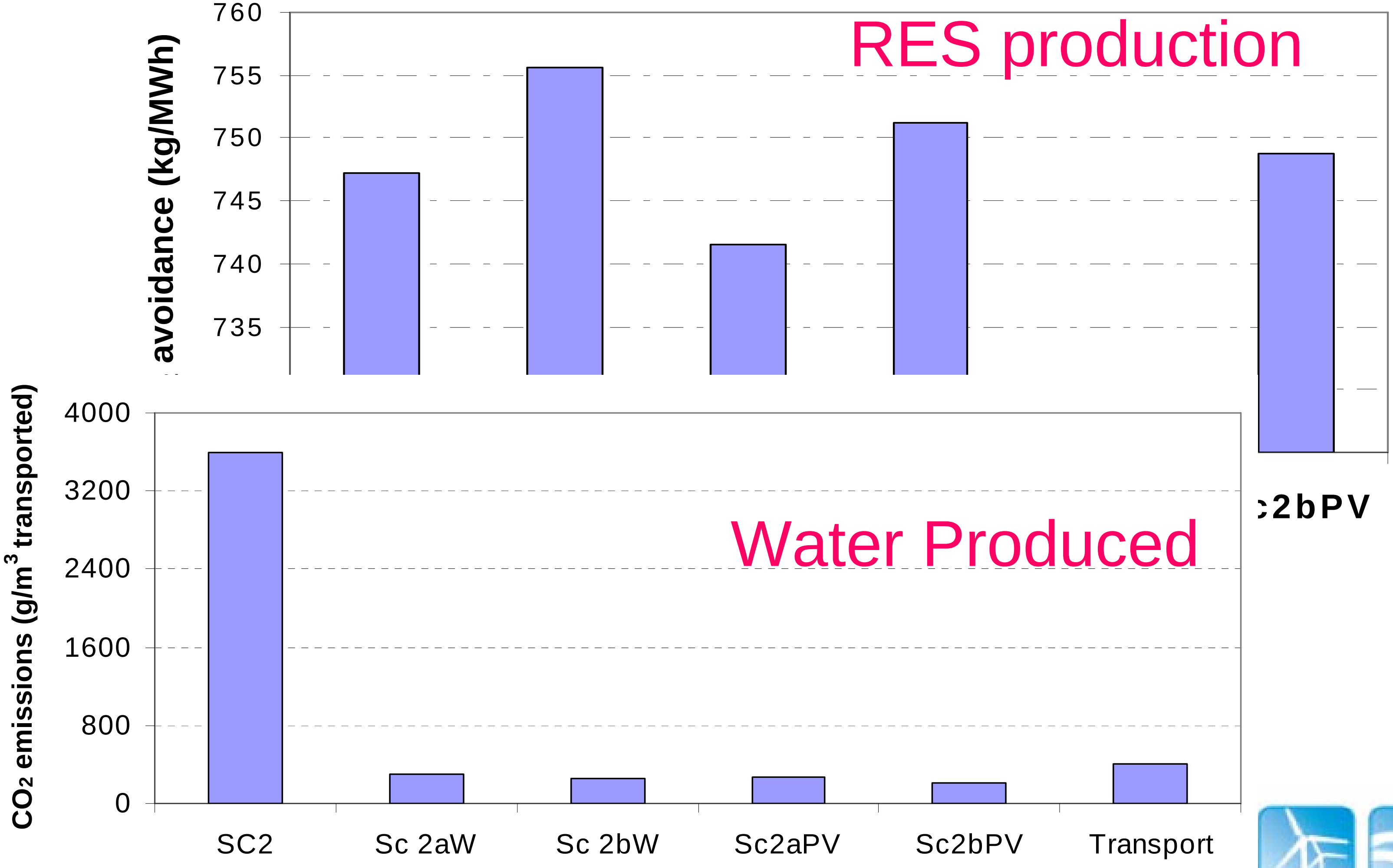
	Without co-operation	With co-operation
Negative Values (Buying from network)	33.7%	26.1%
Zero balance	30%	42.1%
Positive Value (Selling to the grid)	36.3%	31.8%
Confidence interval 95%, [2.5%, 97.5%] (kW)	[-38,51.9]	[-22.7, 42.61]
Frequency within [-20kW, 20kW]	74.5%	91.17%

Mljet-Summary of impact on power system-Scenario 2



- Wind power is assumed on eastern part-justifying losses reduction
  - Co-operation of RES and desalination makes narrower the conf.interval of demand exchanged with rest network
  - PV during peak hours more often sells to the grid than wind

Mljet-Avoided emissions



Mljet-Scenario 1 : Most favourable scenarios

	Most favorable scenario	IRR(%)	Pay back periods(yrs)
Kozarica	Wind -Independent	10.30	11.91
Blato	Wind – autoproducer	10.61	11.57
Sobra	Wind – autoproducer	13.75	8.86

PV can be more favorable if PV-Independent but only for Kozarica is within reasonable time frame

Mljet-Scenario 2 : Project Appraisal Indices

	NPV	IRR(%)	Pay back periods(yrs)
Desalination Only	165,736.47	8.82	13.89
Wind W/O Co-operation	193,435.77	8.97	13.66
Wind with Co-operation	170,615.01	8.64	14.18
PV W/O Co-operation	-5,232.839	5.95	20.17
PV with Co-operation	-41,292.92	5.58	21.40

Mljet-PV tariff change

Update in PV tariff scheme would help in more efficient investment. Not very fair for 30kW to have 13€ct/kWh higher remuneration than 42 kW

$$FIT = FIT_b \cdot \frac{b_2}{Cap} + FIT_c \cdot \frac{(Cap - b_2)}{Cap}$$

b_2:limit of higher tariff e.g.30kW

FIT_b, FIT_c: Tariffs for lower and higher installed capacity

Cap: The PV capacity

	Updated tariff €ct/kWh	IRR(%)	Pay back periods(yrs)
Blato	37.18	4.11	28 vs 61
Sobra	38.02	4.14	28 vs 61
Hotel Odissej PV	33.93	6.45	18.7 vs 21

Desalination-Sensitivity Analysis for Mljet-Sc2

Sensitivity Parameter	***Most Sensitive Scenario***
Interest rate	Sc2bPV
CO_2 emissions trading price	Sc2
Water transfer price	SC2PV
Desalination installation cost	SC2
RES installation cost	Sc2aPV, Sc2bPV
RES prices	Sc2aPV, Sc2bPV
Energy prices	Sc2aPV, Sc2bPV

Mljet Conclusions Desalination

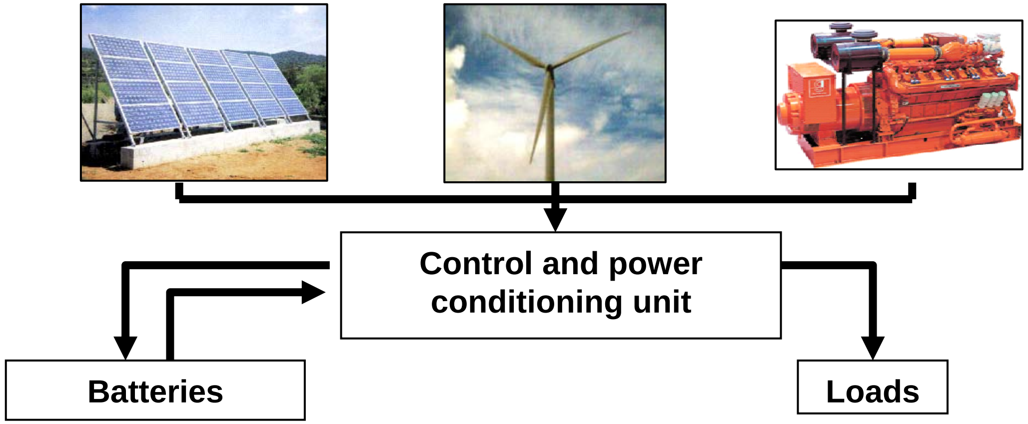
- Addition of RES on the current configuration of the Mljet power system-Scenario 1 can help reducing both power losses and emissions. The value of wind for both the power system and the society is significantly higher. There should be incentives for installations on the eastern part.
- Potential solution for installing wind is use of Geographical Information Systems (GIS) to add constraints of height, distances from natural monuments etc
- If the PVs are installed on the eastern part the losses are even more reduced especially if they are equally distributed to the grid. The additional value for the Croatian power system will be 2€/MWh and 430kg CO_2.

Mljet Conclusions Desalination

- If the major consumer Hotel Odissej installs desalination plant combination with RES will decrease both emissions and network losses compared to adding desalination plant only. Especially m^3 of water delivered below emissions fall below current transport levels.
- However, co-operation of RES in desalination schedule will provide limited benefits both for the owners and the society. Clearly is not as effective as Milos case study. Power exchange will be in narrower limits especially for PVs
- Change in PV tariff system to be more proportional to installed capacity will help the owners more easier pay back their investment.
- Benefit to Cost Ratio for society is low since mostly private entities are affected. Moreover, the suggested development plans are limited.

Typical Configuration of battery system Mljet

The microgrid will combine photovoltaic, wind and diesel systems to supply, in a stand alone mode



16MWh batteries

2 scenarios regarding wind power installed capacity

a. Around 1.6MW b. About half of them

4 scenarios regarding height of the nacelle

Also contact Dr Suarez Carcia ssuarez@itccanarias.org

Mljet and battery results

2 Diesel units 600kW and 300kW –1MW PV

Height of W/Ts	24m	35m	44m	73m
Number	50	13	5	2
Installed capacity (kW)	1650	1625	1650	1620
RES penetration(%)	80.32	77.17	80.71	82.76
Wind power curtailment (%)	30.8	27.6	33.8	34
Cost of Energy (€/kWh)	0.402	0.41	0.384	0.382
Fuel Consumption (tn)	322	374	316	282

Mljet and battery results-low penetration

2 Diesel units 700kW and 400kW –1MW PV

Height of W/Ts	24m	35m	44m	73m
Number	25	7	3	1
Installed capacity (kW)	825	875	990	810
RES penetration(%)	71.01	68.06	73.71	72.76
RES curtailment (%)	10.2	10.1	16.7	11.3
Cost of Energy (€/kWh)	0.418	0.429	0.401	0.405
Fuel Consumption (tn)	470	517	429	443

Final Remarks-Mljet and Batteries

- Wind power can help significant in increasing RES penetration on the island.
- Large hub heights can increase RES penetration and decrease number of wind turbines
- Excess electricity is at least 28% and increases with hub height for high wind power installed capacity
- If wind power capacity is reduced, RES penetration is reduced by about 10% and the excess electricity is limited below 17%.
- Cost of Energy and fuel consumption is reduced with hub height and increases as wind power capacity is reduced.

Further proposals-Mljet

- Adding RES and batteries can help Mljet operate as a Microgrid if the interconnection with mainland remains.
- Batteries in such a case can provide aid for increasing local reliability helping the system operating autonomously if the interconnection is lost
- More information on Microgrids and results from similar examples can be found on www.microgrids.eu (MICROGRIDS and MORE MICOGRIDS projects)

Greek islands

- 1,000,000 citizens living
- 8% of energy consumption
- Almost double percentage of increasing demand
- Fuel units based on imported fuel oil
- PPC is the operator of the islands, RES pricing-450-500€/MWh PVs & 84.6 €/MWh for the rest

Installed	Wind Power (MW)	Small Hydro (MW)	Biomass (MW)	PV (kW)
Crete	***160.0***	**0.6**	**0.4**	**670**
Cyclades	***9.81***	**0**	**0**	**182**
Dodecanesse	***30.05***	**0**	**0**	**38**
Rest Aegean Islands	***30.22***	**0**	**0**	**73**
Total islands	230.08	0.6	0.4	963

Current State of Autonomous Power Stations and Interconnections in the Aegean Sea

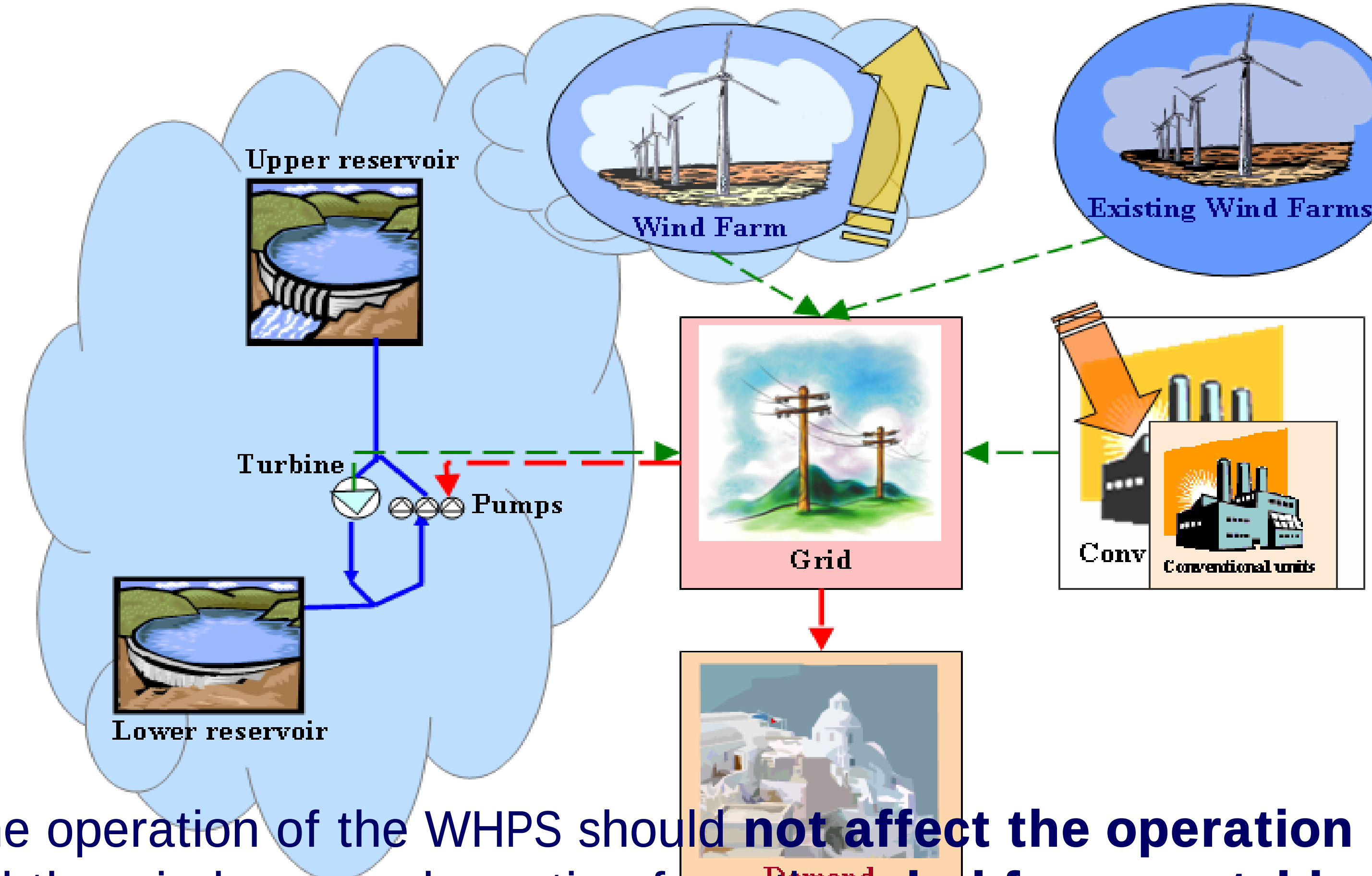
Conclusions Other cases than the ones in STORIES

- Kythnos and Crete had been studied before starting STORIES project
- On Kythnos,Battery bank decreases number of intervals with possible insecure operation at lower cost compared to operate an additional unit
- Elimination of load interruption when energy storage is available without significant increase in operating cost compared to most economic scenario.
- Management of an energy storage system helps in
  - Reducing operating cost
  - Improving security indices
  - Reducing RES power curtailed
- Crete : Storage can help in reducing the uncertainty of forecasting and thus with relatively low capacity, the cost is significantly decreased

More details in Gran Canaria workshop

Wind energy with hydro Pumped Storage

General concept



The operation of the WHPS should **not affect the operation** and the wind power absorption from the **wind farms outside** of the hybrid system

Pumped storage – IOS general characteristics

Short description of the case study	- part of a medium size autonomous grid comprised by several islands
Prospects of interconnection	- prospects of interconnection with the mainland
Why to introduce a WPS system in this system?	- Rather medium current electricity production cost - centralized system - existing reservoir - suitable topography for the construction of the upper reservoir
Drawbacks of WPS or main technical obstacles to be considered	- transport capacity of underwater cables

Operational design	- wind power supplies the power demand with respect to the technical constraints of the autonomous system and the wind power surplus is used for pumping.
Target	- a rather medium contribution
Prospects of WPS to reduce the current electricity production cost	- Neutral. The EPC will be slightly decreased thanks to the WPS integration
Priority for the implementation	- high

Pumped storage – Case study: IOS

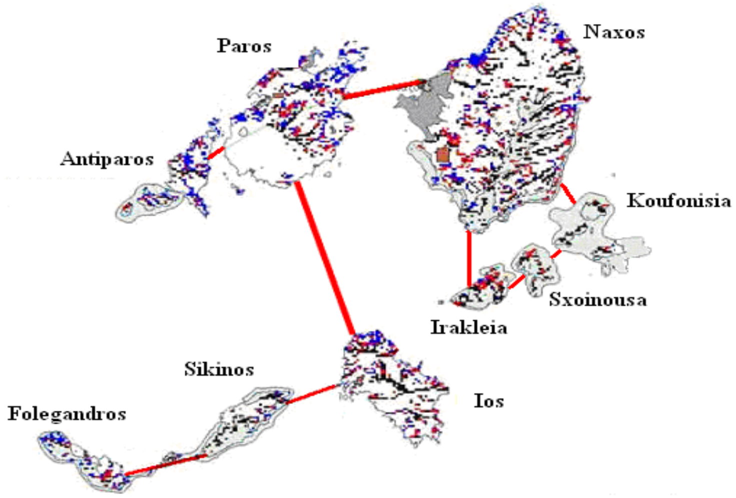
✓ RES supply in Paro-Naxia: 16.6% (with wind) => 23.9% (with WHPS)

✓ EPC 54$/b : 0.127 => 0.121€/kWh

✓ EPC 100$/b: 0.192 => 0.171€/kWh

(CO_2 emissions cost – not included)

✓ Investment cost: 18.8 million €



Hydro turbine	8MW
Wind farm (in the hybrid)	8MW
Pumps	8*813kW=6,5MW
Capacity of the lower (existing) reservoir	230000 m^3
Capacity of the upper reservoir (to be constructed)	120000m^3

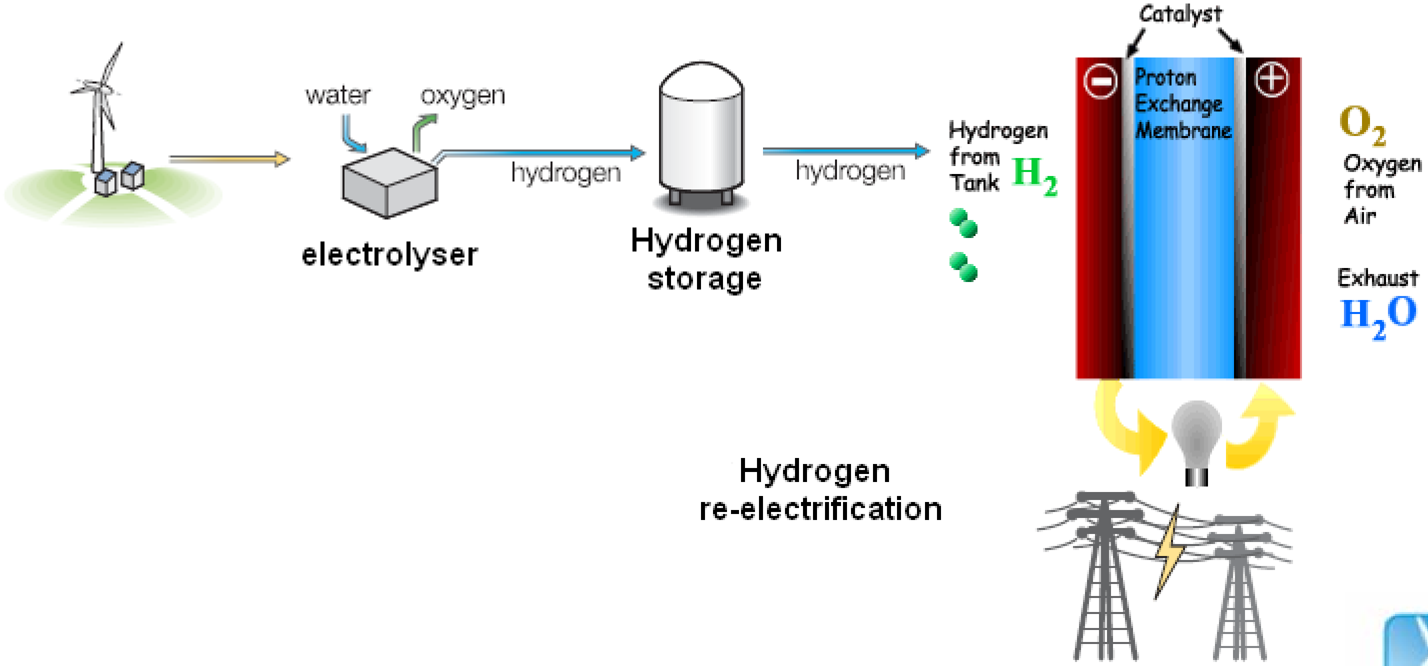
Price of hydro electricity sold to the grid (€/kWh)	0.15
IRR	22,32%
PBP (years)	5,6
NPV(i=9%) (1000€)	8931

Pump Hydro Conclusions-Ios

- ✓ Generally:
  - ➢Additional constraints by the current grid infrastructure between islands
  - ➢ WHPS is a good solution to make the first step towards a larger renewable penetration. Since helps in reducing wind power curtailment.
  - ➢ WHPS will contribute to the decentralization of the current system and improve the stability and the power quality of the system.
- ✓The probable financial benefit from the introduction of the WPS should be shared between the ESO and the investor, by the definition of a suitable price.
- ✓The production cost is known in advance, not depended on oil price variations.
- ✓ The installation of WPS provides both financial and environmental benefits

Contact Person Dr Caralis gcaralis@central.ntua.gr

Hydrogen



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Milos -Overview

- 5000 population-5 times higher during summer
- 8 Thermal Units
  - 2 Sulzer (1,75 MW Oil-fired)
  - 3 MAN (0,7 MW Oil-fired)
  - 1 CKD (2 MW, Diesel)
  - 1 CKD (1,9 MW, Diesel)
  - 1 FINCANTIERI (1,75 MW, Diesel)

Renting units for summer periods

- 3 W/T
  - 2 Vestas V – 44 (0,6 MW)
  - 1 Vestas V – 52 (0,85 MW)

Homer software used for sizing/simulations

INTRODUCING 10% H_2 (peak) in Milos

- 4+1 Generator Sets

2 Sulzer 7TAF48 Units (1,75 MW each, Heavy Oil)

2 MAN G9V30/45 Units (0,7 MW each, Heavy Oil)

1 Rental Unit (1 MW, April - September)

- 30 Wind Turbines

2 Vestas V – 44 (0,6 MW each)

28 Vestas V – 52 (0,85 MW each)

Electrolyser (2 MW)

PEM Fuel Cell (1 MW)

Hydrogen Tank (3.000 kg)

Milos & Hydrogen-Basic Inputs

- Heavy Oil Price: 0,34 €/L
- Diesel Price: 0,68 €/L
- Generators Capital Cost: 250 – 300 €/kW
- Wind Turbines Capital Cost: 1.000 €/kW
- Electrolyser Capital Cost: 2.000 €/kW
- PEM Fuel Cell Capital Cost: 3.000 €/kW
- Hydrogen Tank Capital Cost: 1.000 €/kg
- Project Lifetime: 20 years
- Subsidy Scheme (30% for wind turbines and 50% regarding Hydrogen technologies)

SUMMARY – COMPARISON-Hydrogen

Parameter	Milos Power System	Introducing 10% H2
COE (€/MWh)	113	112
Renewable Fraction	13.4	86
Diesel (L)	715.296	147.308
Heavy Oil (L)	8.108.687	3.276.838
CO_2(kg/yr)	26.934,542	10,095,664

Contact also Co-ordinator team Dr Zoulias mzoulias@cres.gr

CONCLUSIONS-Milos-Hydrogen

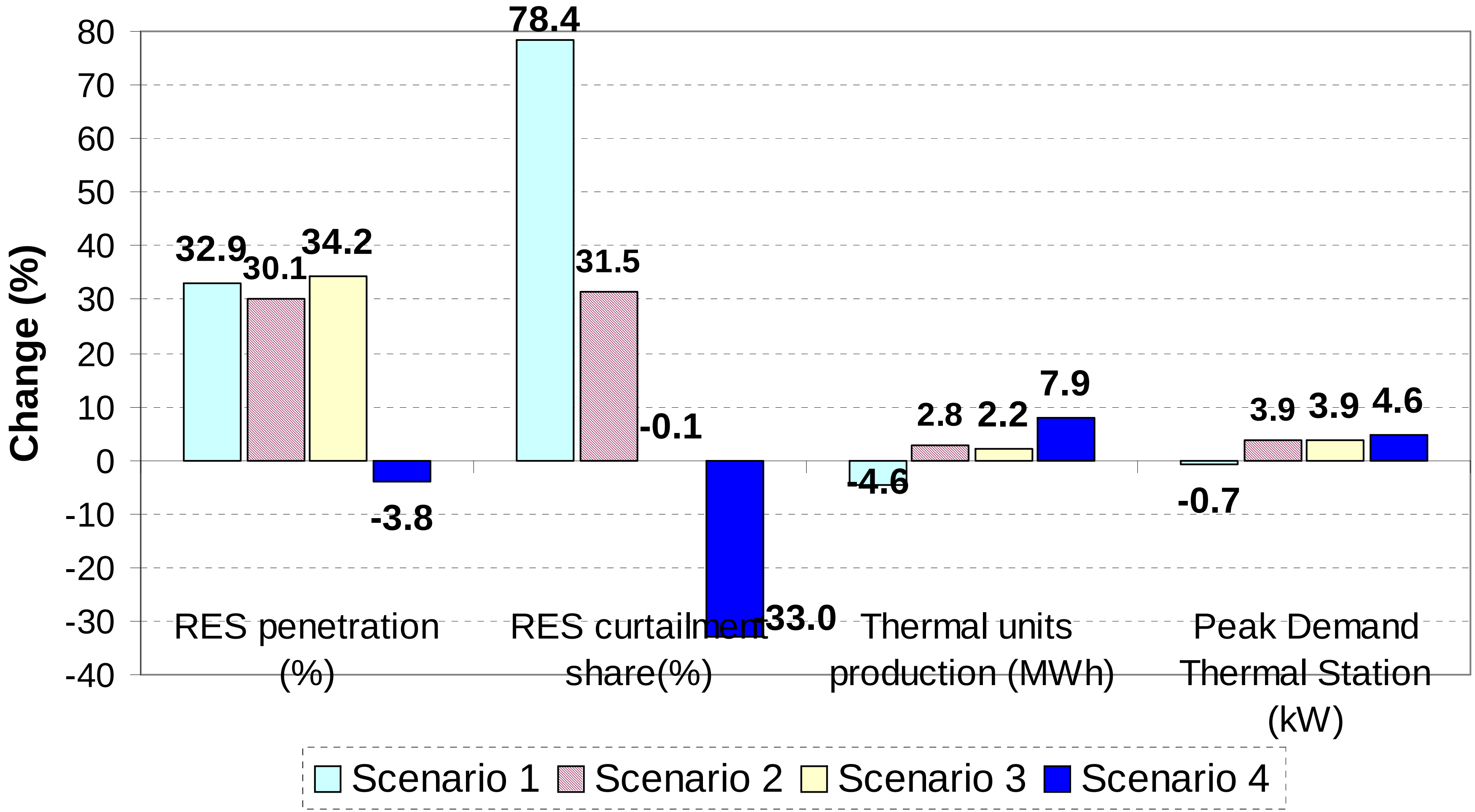
The introduction of hydrogen as energy storage method in Milos results in:

- huge increase on RE penetration on the island (from 13% to 85%)
- significant reduction in fossil fuels consumption (ca.over 50%)
- significant reduction in emissions produced (especially in CO_2, ca. over 50% for all pollutants)
- further reduction on the cost of hydrogen energy equipment and the introduction of external costs makes the hydrogen-based system economically competitive to the existing one.

Milos- Desalination- Scenarios studied and assumptions

- Addition of W/T 850kW with additional production 2.2GWh
- Desalination
  - 4 identical units of $84m^3/h$ and electrical demand 150kW.
  - $3000m^3$ water tank. Meeting double the annual transferred quantity- $406000m^3$.
  - Represents 6.8% of the annual consumption of the island –2.9GWh.
- Scenarios
  - Addition of one wind turbine -SCEN 1
  - Addition of one wind turbine +desalination with independent scheduling-SCEN 2
  - Addition of one wind turbine +desalination with co-operation in scheduling SCE 3
  - Addition of desalination plant only.-SCEN 4

Comparison with current situation



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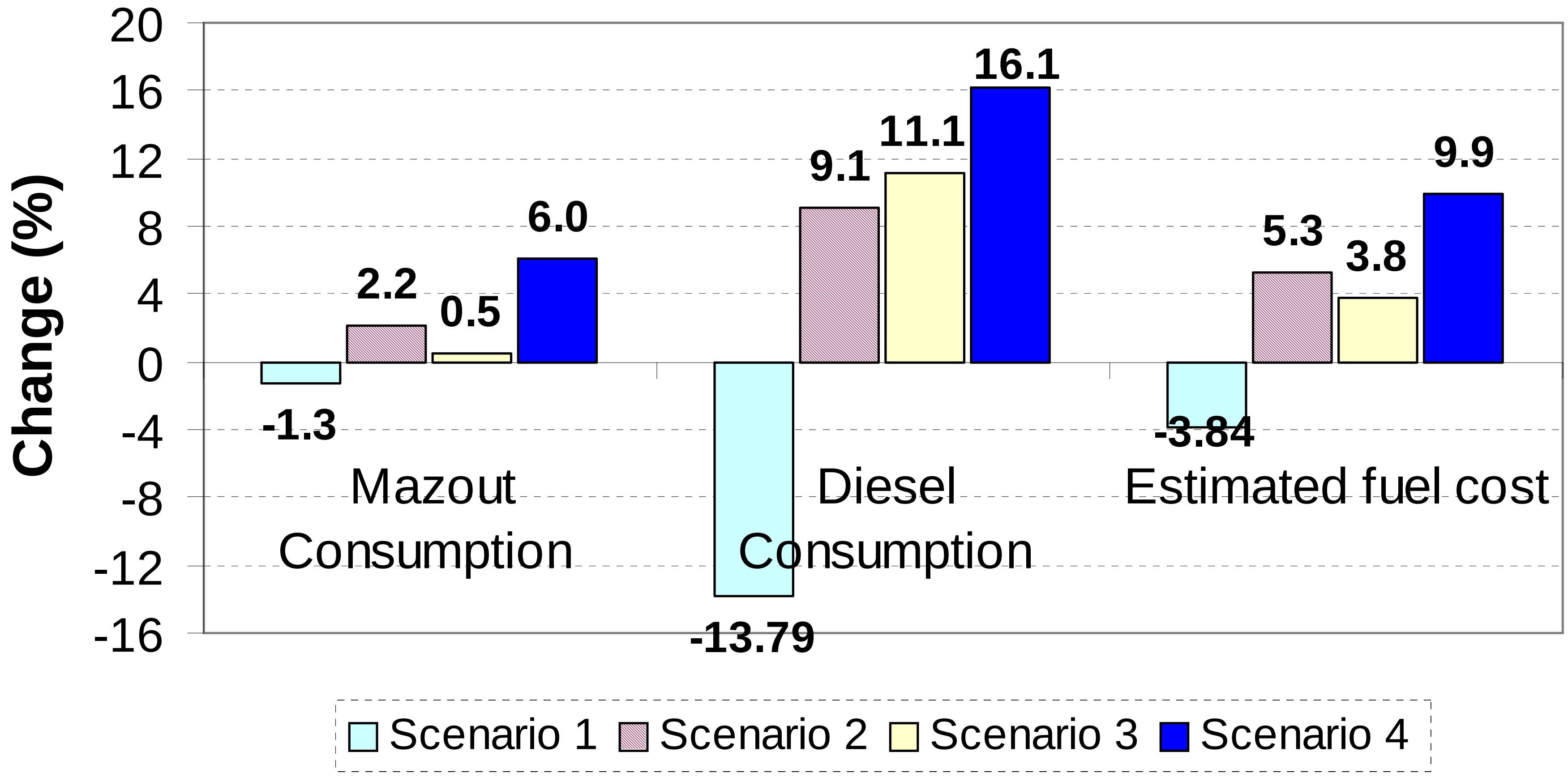
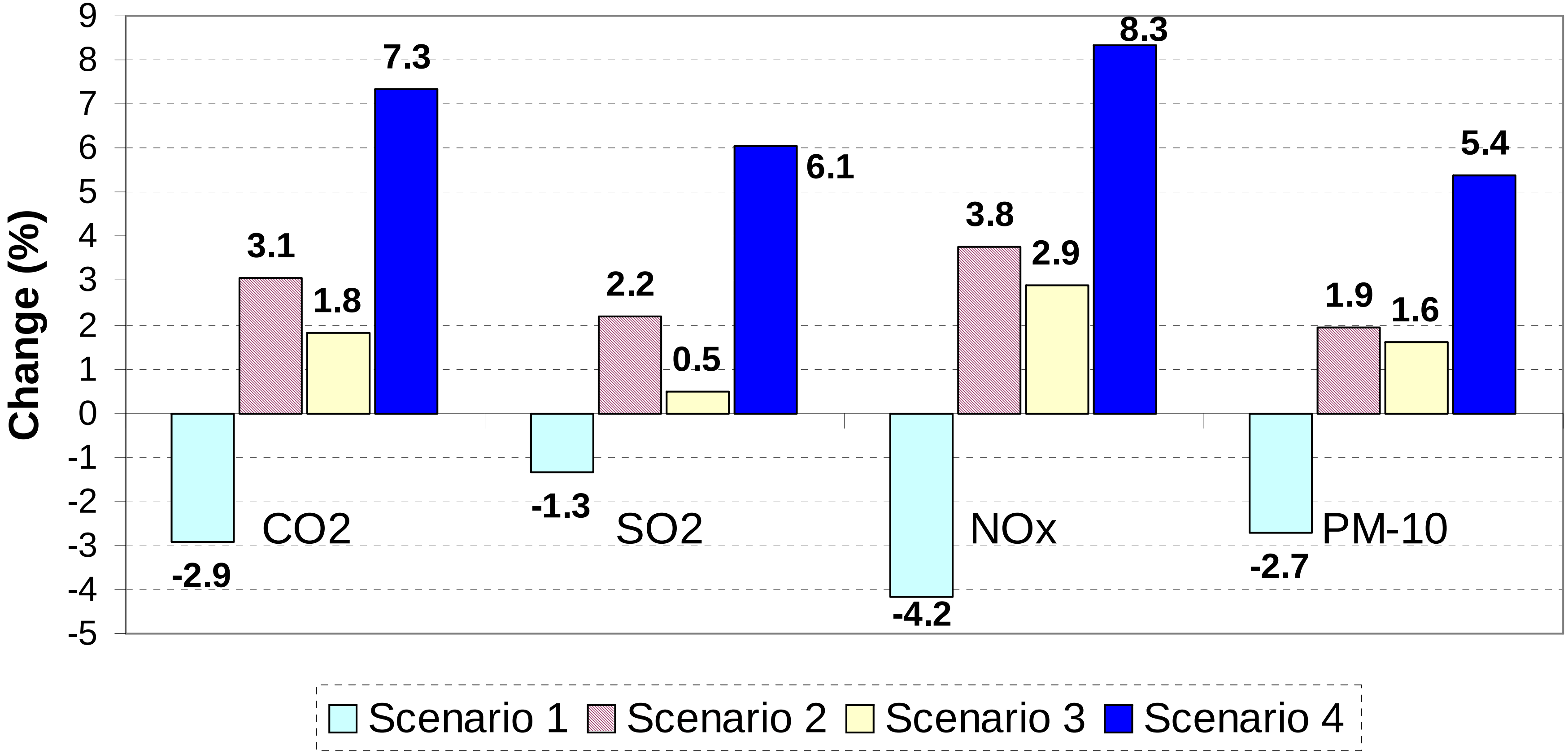
Comparison with current situation Fuels&Cost



Comparison regarding emissions-Milos



Summary of results-Milos –Desalination

	Current Situation	SCE 1	SCE 2	SCE 3	SCE 4
Fuel Cost(k€)	2778.9	2672.2	2925.7	2883.3	3052.5
Wind power curtailment (%)	8.9	15.88	11.7	8.89	5.96
Wind power injection (MWh)	4887.6	6498.5	6821.4	7038.1	5045.5
Wind power penetration(%)	12.3	16.35	16	16.51	11.83

CONCLUSIONS-Desalination Milos (I)

- Desalination provides water at significantly lower prices (1/4th of the current cost)
- If installed at the same period with RES under medium –high penetration :
  - Reduces wind power curtailment with benefits to the owner of the existing wind park even if he does not make any investment compared to previous case
  - Decreases significantly compared to no RES addition:
    - The additional demand for the power system
    - The power system fuel cost
    - The emissions

CONCLUSIONS Desalination Milos (II)

- Co-operation of RES and desalination during the scheduling
- According to the current tariff scheme for loads in MV is not favorable but :
  - The fuel cost for the operator of the island is reduced.
  - The company of the additional or existing wind park (depending on who invests) increase their profits.
  - Both (company&operator) can reduce their profit to compensate for this difference and still have profit.
  - The municipality meets the water demand at lower emission levels.

More information on these 3 cases see Athens Workshop presentations and Deliverables D2.1 and D2.3

Final Remarks-Energy Storage

- Energy storage in island systems with increased RES penetration cannot only help in reducing the insecure operating points but also in decreasing the operating cost.
- Development of algorithms for energy storage optimization of use help reducing the operating cost of Autonomous Power systems much more.
- Hydrogen can be a viable solution for island communities even if used for electricity only.
- Controllable loads like desalination loads can provide significant aid in reducing RES curtailment on island providing simultaneously potable water.

Thank you for your attention

NTUA

atsikal@power.ece.ntua.gr

www.storiesproject.eu contains deliverables with further information on the issues described here