



Operation of a Hybrid Power Station in an Isolated Power System: The Case of Samos Island

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Introduction

- The majority of Greek islands in Aegean Archipelagos are not interconnected with country's continental system
- The electricity market of these islands consists of 32 isolated systems, which can be included in the following categories:
 - “Small” systems with peak demand up to 10 MW (contains 19 systems)
 - “Medium” systems with peak demand from 10 MW to 100 MW (contains 11 systems)
 - “Large” systems with peak demand exceeding 100 MW (contains 2 systems)



Isolated power systems

- In many of these islands, there are significant amounts of wind and solar potential, so technologies based on renewable energy sources (RES) can be used
- Main differences with interconnected systems:
 - Low minimum to maximum demand ratio
 - Larger frequency deviations are presented with relatively small production or demand changes
 - Operational cost of conventional generators can be high – in many cases exceeds 200 €/MWh
- The operation of isolated power systems with significant RES penetration can be improved significantly by the installation of a large scale energy storage system

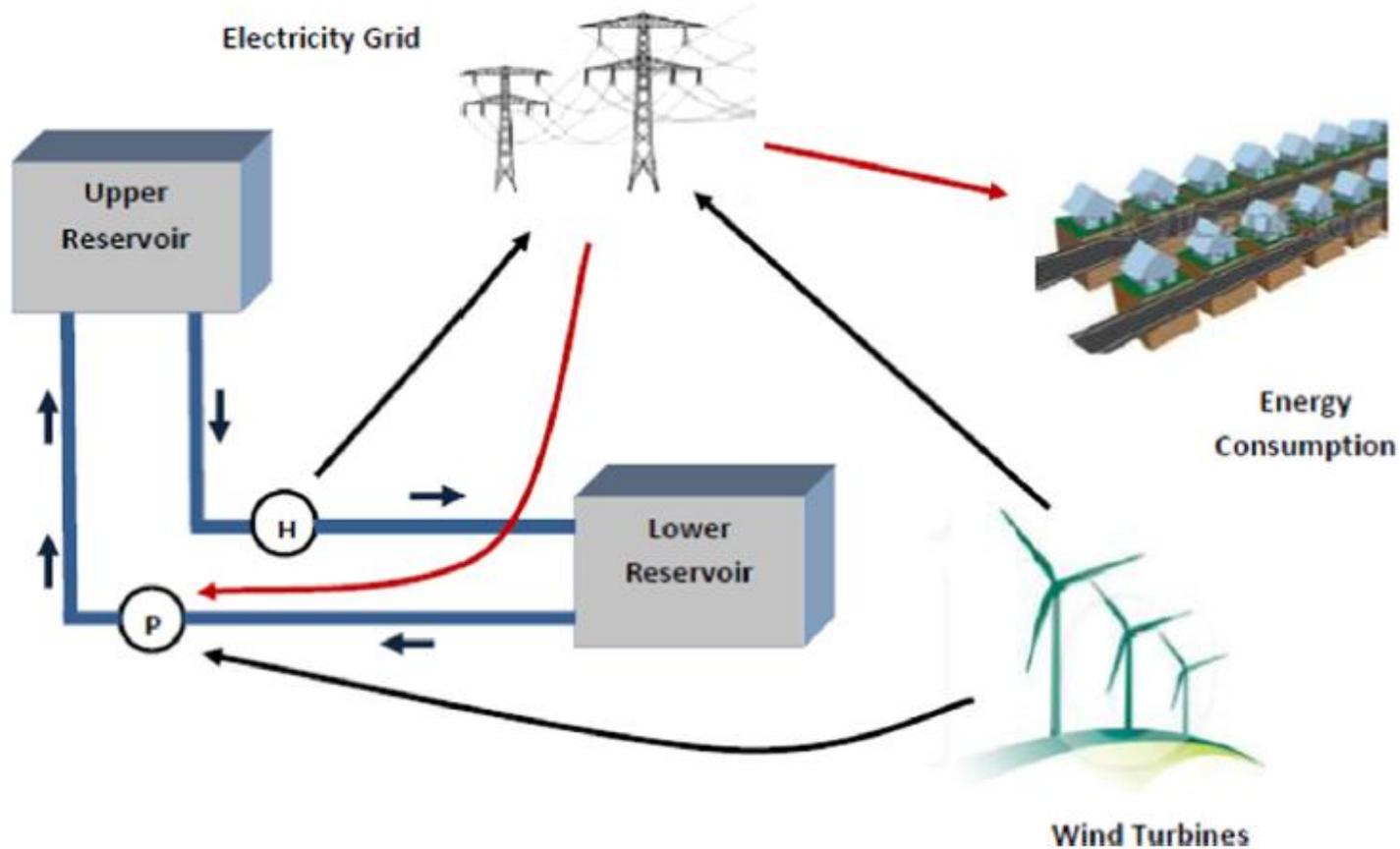


Scope of Presentation

- This paper studies the effect of installing a hybrid power station in the medium sized isolated power system of Samos Island
- Hybrid power station combines pumped hydro storage (PHS) and newly installed wind turbines (WTs)
- Evaluation is performed in hourly time steps for a whole year using real data
- The performed analysis studies the economic viability of this project under different billing scenarios, as well as its impact to the isolated power system operation



Structure of a PHS-WT hybrid power station





Outline

- Hybrid power stations framework in Greece
- Description of the isolated power system of Samos Island
- Main considerations and scenarios
- Evaluation of results



Hybrid stations framework in Greece

According to the Greek legislative framework, a hybrid station is a power generation plant that:

- Uses at least one form of RES technology
- The total amount of electricity taken in from the Network on an annual basis cannot exceed 30% of the total amount of energy consumed for the filling of the storage system of that station
- The maximum output of the units of the RES station should not exceed the installed of that station increased by 20% at the most



Restrictions in hybrid stations operation

- Daily produced energy has to be at least 2 hours $\times P_{hydro}$ (P_{hydro} : maximum power output of the station)
- In certain days (especially with high loads) the hybrid station has to provide its guaranteed energy (in our case $P_{hydro} \times 8$ hours)
- If the total power output of the WTs is less than the pump installed capacity of hybrid power station P_{pump} , the total generated wind power can be stored in hybrid power station with respect to reservoirs upper and lower limits
- If the total power output of the wind farms is greater than P_{pump} and less than $1.2 \times P_{pump}$, the amount of wind power that cannot be stored can be provided directly to the grid, if it is feasible



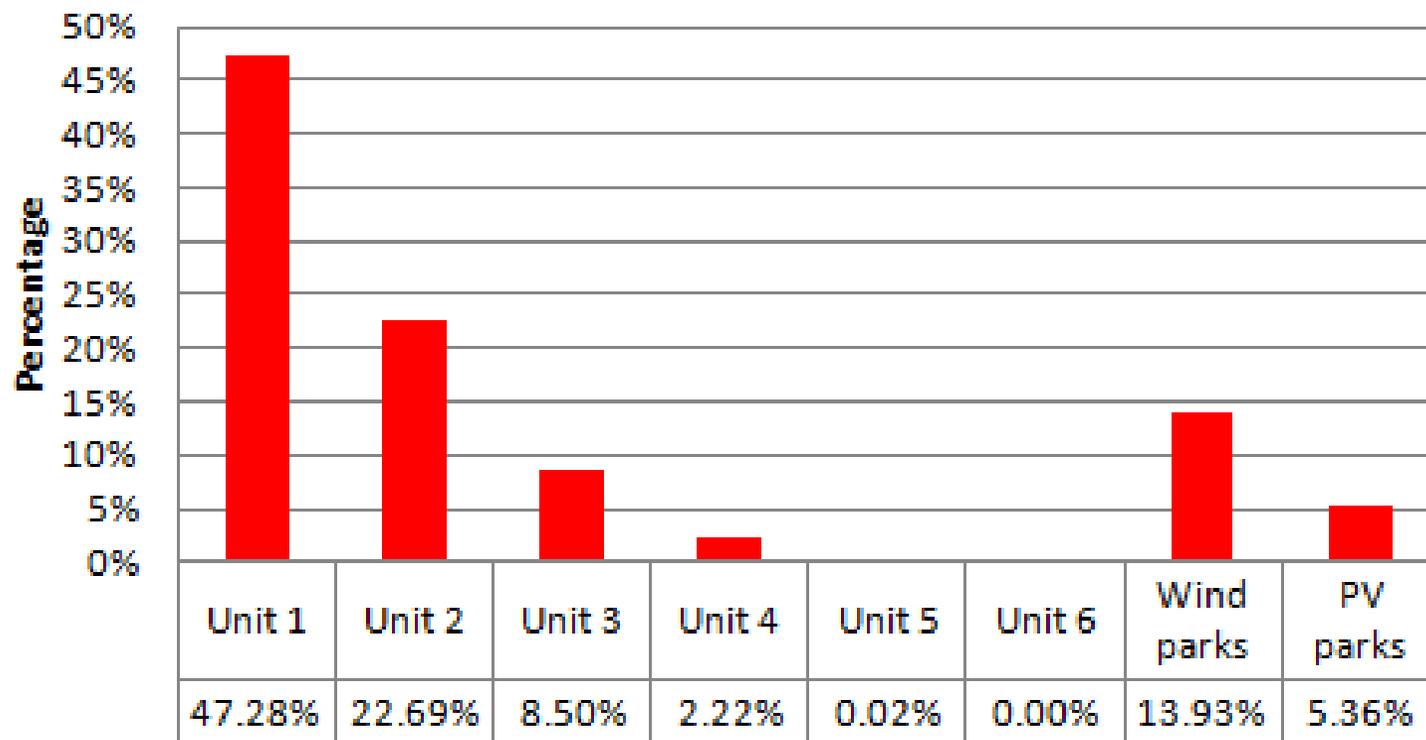
Samos Island power system characteristics

- One power station that consists of six mazut fueled diesel generators, with total installed capacity of 47.75MW
- 15kV medium voltage (MV) overhead lines distribution network
- 2015 year data: peak net load 30.2MW, base net load 7.56MW, annual electricity demand 140GWh
- Total installed capacity of existing WTs: 7.975MW (annual capacity factor (CF): 29.38%)
- Total installed photovoltaics (PV) power: 4.486MW (annual CF: 17.70%)



Annual energy production share in Samos Island

Annual energy production per source





Main considerations

- Pump efficiency: 78%, hydro efficiency: 90% → total efficiency of PHS unit: $n_{total} \approx 70\%$
- P_{pump} is considered to be equal to P_{hydro} / n_{total}
- Annual CF of newly installed WTs is equal to annual CF of already installed WTs (i.e., 29.38%)
- Maximum allowable WT penetration: 50% of net load
- Guaranteed energy from hybrid power station is provided at the days of the year in which their daily consumption is greater than 90% of the annual maximum daily consumption (34 days per year)
- PHS station reservoir capacity: $P_{hydro} \times 14$ hours



Economic assumptions

- PHS unit installation cost: 3,000,000 €/MW
- WTs installation cost: 1,200,000 €/MW
- 70% of these installation costs are covered from a bank loan of 6% interest rate and 20 years duration
- Annual operational and maintenance (O&M) costs: 1.5% of total installation costs
- PHS unit and hybrid power station lifetime: 50 years
- WTs lifetime: 25 years (replacement on the 26th year)
- Net present value (NPV) is calculated with discount rate $i=8\%$



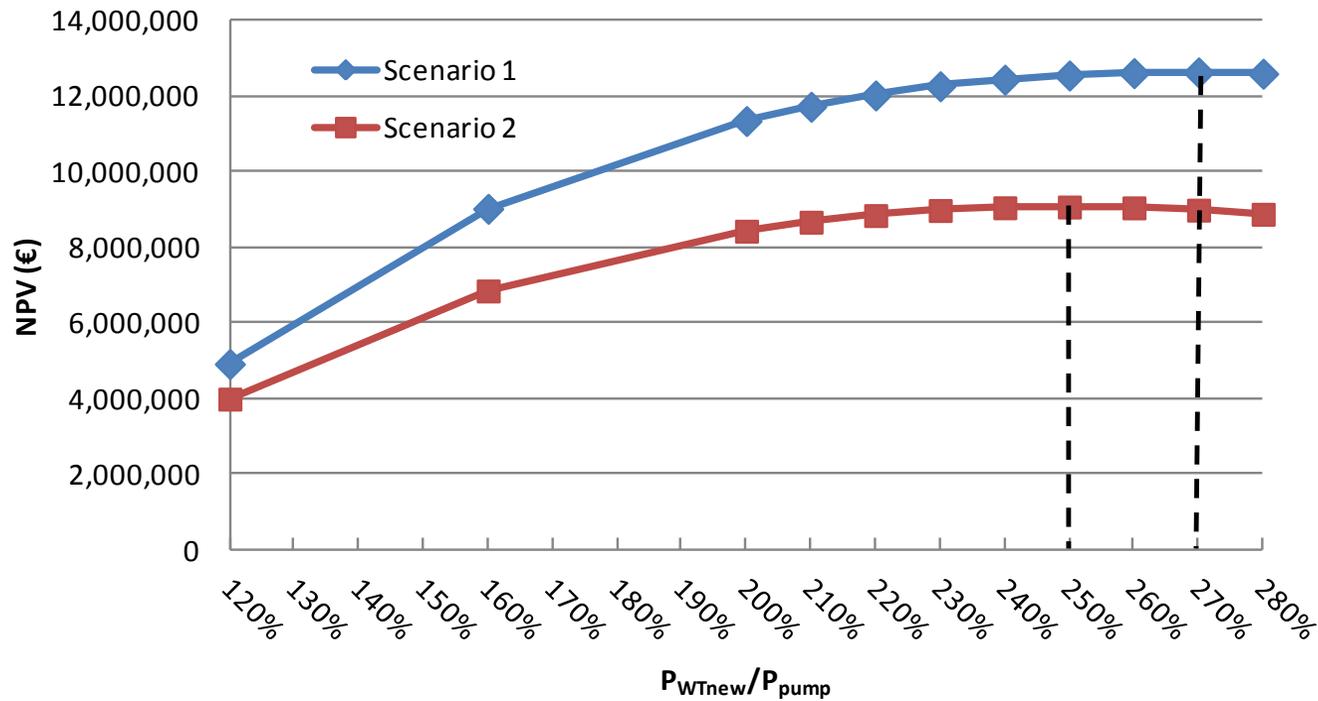
Financial schemes and PHS size considerations

- Two alternative financial schemes are examined:
 - *Scenario 1*: Energy delivered by PHS to the grid is paid 200 €/MWh. Energy absorbed from grid has a cost of 140 €/MWh, ($=200 \times n_{total}$ €/MWh)
 - *Scenario 2*: Energy delivered by PHS to the grid is paid 147 €/MWh and PHS power availability is paid annually 127,000 €/MW. Energy absorbed from grid has a cost of 103 €/MWh, ($=147 \times n_{total}$ €/MWh)
- Electricity from newly installed WTs that cannot be absorbed by PHS but it is absorbed by the grid (if maximum wind penetration is not surpassed) is paid for 98€/MWh
- Three PHS sizes are examined: 1) $P_{hydro} = 3.5\text{MW}$, 2) $P_{hydro} = 7\text{MW}$, 3) $P_{hydro} = 10.5\text{ MW}$



Optimal PHS scenario with $P_{hydro} = 3.5$ MW

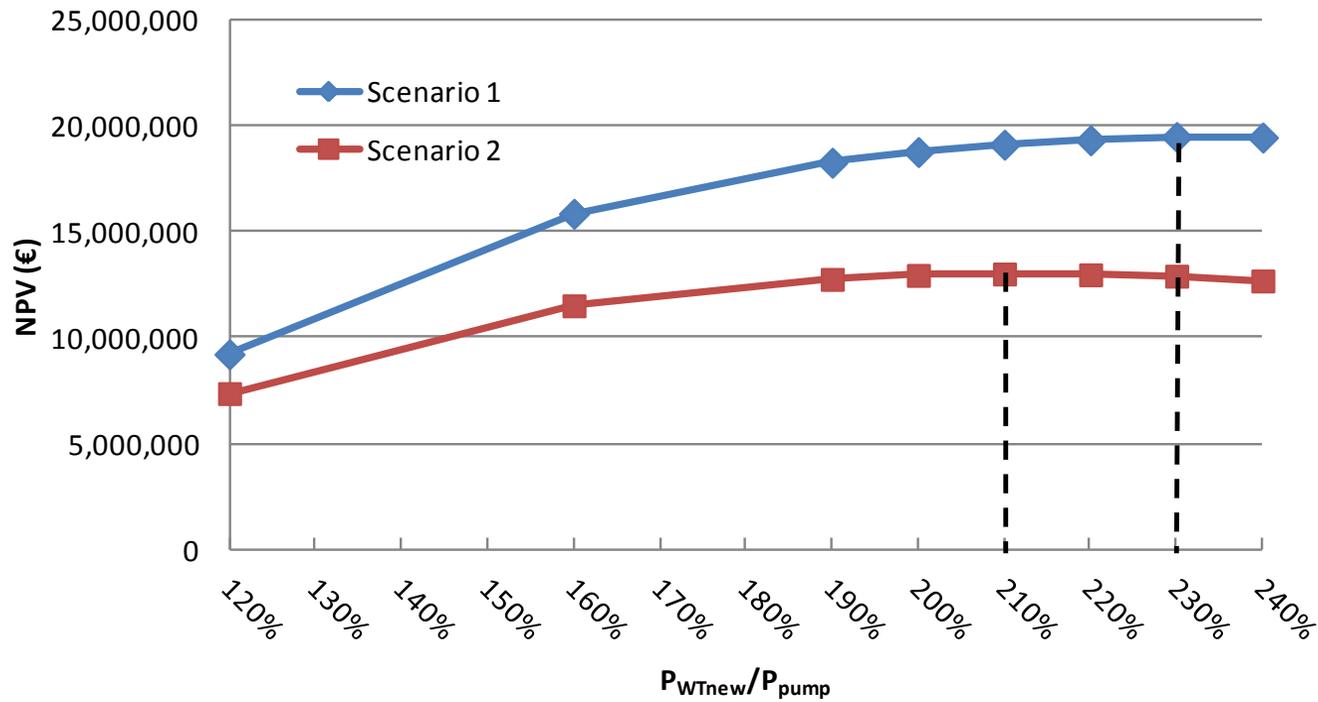
3.5 MW Hydro Capacity





Optimal PHS scenario with $P_{hydro} = 7.0$ MW

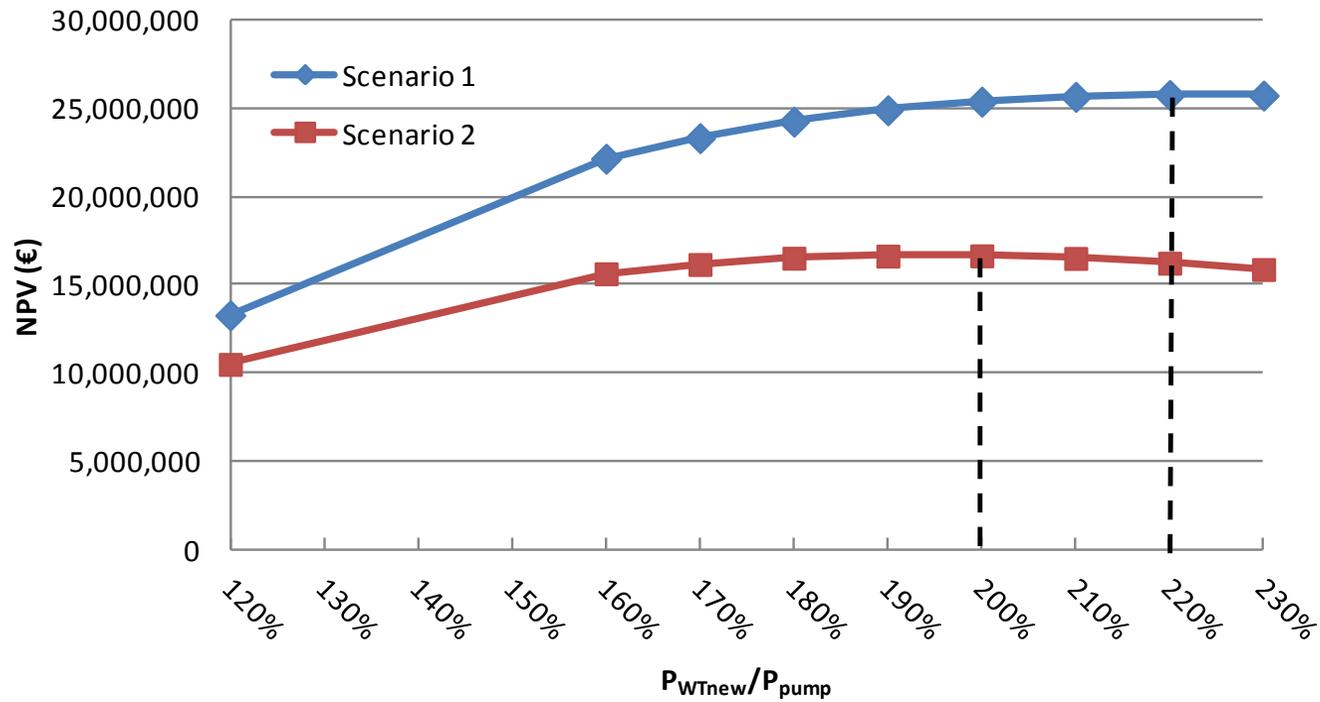
7.0 MW Hydro Capacity





Optimal PHS scenario with $P_{hydro}=10.5$ MW

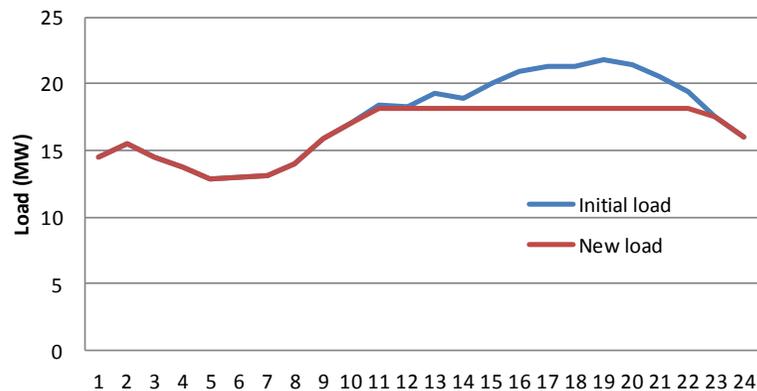
10.5 MW Hydro Capacity





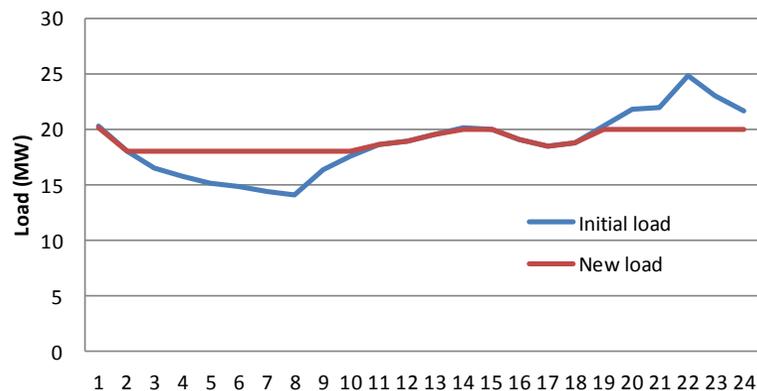
Scenario 1 with $P_{hydro} = 7.0$ MW: Load curve effect

Peak shaving



Day 4 of the year

Peak shaving + Valley filling



Day 205 of the year



Effect on power system operation (Scenario 1)

$$P_{hydro} = 3.5 \text{ MW}$$

- Hybrid station: 15.10% of total electricity (9.78% from PHS, 5.32% from new WTs)
- Electricity taken from the Network (valley filling): 1.05% of total amount of energy consumed for the filling of the storage system
- Wind power curtailment (new WTs): 25% of wind power that absorbed by pumps
- Annual operating cost of conventional units: 8,062,833 € (18.5% lower from initial cost)



Effect on power system operation (Scenario 1)

$$P_{hydro} = 7.0 \text{ MW}$$

- Hybrid station: 24.48% of total electricity (18.89% from PHS, 5.59% from new WTs)
- Electricity taken from the Network (valley filling): 1.27% of total amount of energy consumed for the filling of the storage system
- Wind power curtailment (new WTs): 24% of wind power that absorbed by pumps
- Annual operating cost of conventional units: 6,988,914 € (29.3% lower from initial cost)



Effect on power system operation (Scenario 1)

$$P_{hydro} = 10.5 \text{ MW}$$

- Hybrid station: 33.89% of total electricity (28.01% from PHS, 5.88% from new WTs)
- Electricity taken from the Network (valley filling): 1.33% of total amount of energy consumed for the filling of the storage system
- Wind power curtailment (new WTs): 25.2% of wind power that absorbed by pumps
- Annual operating cost of conventional units: 6,032,105 € (39.0% lower from initial cost)



Summary

- The impact of a WT-PHS hybrid power station in the operation of the medium sized isolated power system of Samos Island is studied
- Two available billing options for PHS operation were compared: Scenario 1 was superior in all cases
- The projects are economic viable
- Significant penetration of hybrid power station (mainly from PHS)
- Remarkable fuel savings in conventional generators operation
- *Next step:* More detailed sizing, sensitivity analysis, power flow studies



Thank you for your attention!