Integrating Intermittent Renewables

Challenges and Solutions

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Outline

- Introduction
- Operational Issues
- Market and Regulatory Issues
- Conclusions

Electricity system: design, operation and market components

- Energy
- Ancillary services
  - Operational reserve in different time scales
    - Primary (ms, sec)
    - Secondary (sec, min)
    - Tertiary (min)
    - Replacement (hours)
    - Contingency (hours, 1 day)
  - Frequency control, Voltage control (reactive power), Black Start capability
- Capacity (generation adequacy)

RESe: Part of the Solution

The world community, and the EU in particular, promotes renewable energy sources because their use reduces:

- CO_2 emissions
- Pollutants (NOx, SOx, particulates ...)
- Dependency on imported fossil fuels (security)
- Eventually, energy cost

Intermittent RESe: Operational Issues

- Solar (PV) and Wind RESe are intermittent, non-dispatchable, and have low predictability (they generate when the wind blows and the sun shines).
  - Generation during low demand periods pushes thermal generating units to their technical limits and requires shutting down of thermal units
  - High ramp rates require additional fast response from dispatchable units (or the demand side). Thermal stresses and wear on thermal units.
  - Voltage and Current harmonics
  - Generation predictions not accurate (≈30% error for wind). Sub-optimal commitment scheduling

RESe: Market Issues

- Priority in access to the system to RES generation
  - Lower load factors of conventional units
  - Reduced marginal prices. Lowers income for generators with conventional generation
- Firm capacity contribution of intermittent RESe is low
  - Investments in firm capacity are required to back-up renewables

Regulatory issues

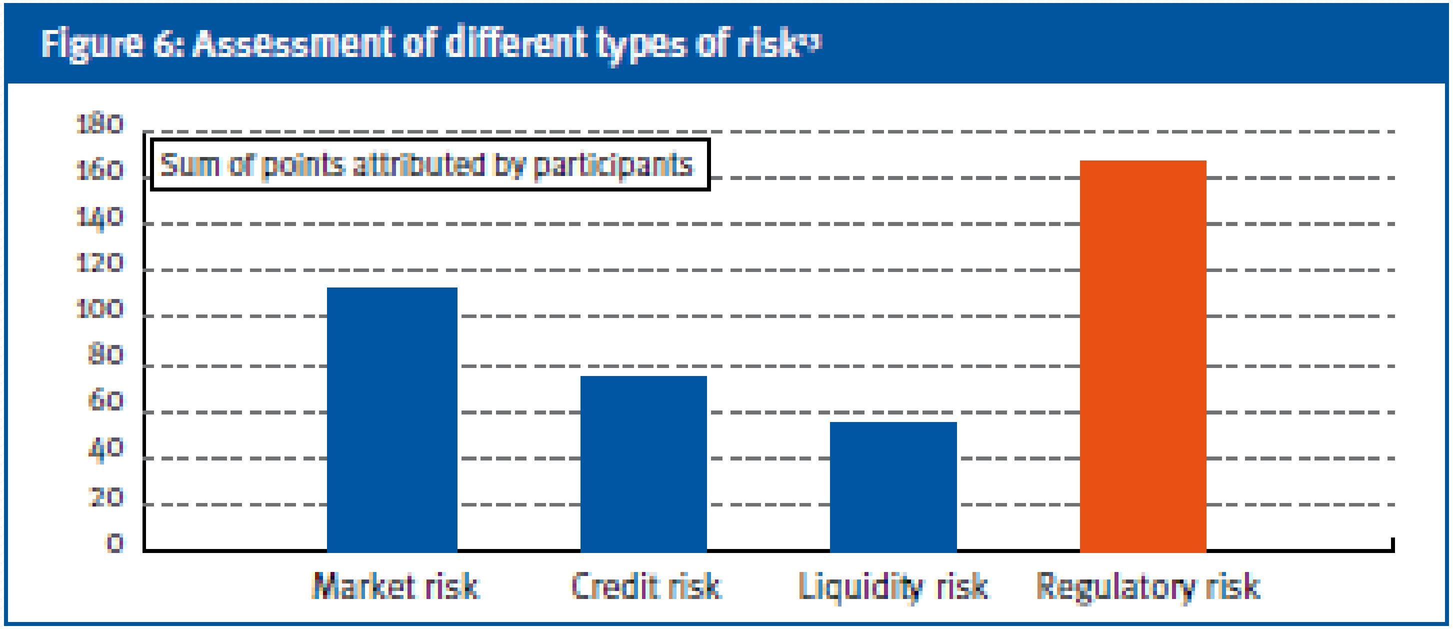
- A conglomerate of national, European, and international environmental

  directives, protocols, targets, schemes, incentives,

  market tools, regulations, mechanisms, plans .....

  towards promoting RESe and environmental protection
- Sometimes contradicting targets (e.g. Water Framework directive vs. need for flexible generation)
- Volatility in regulation = uncertainty in investment

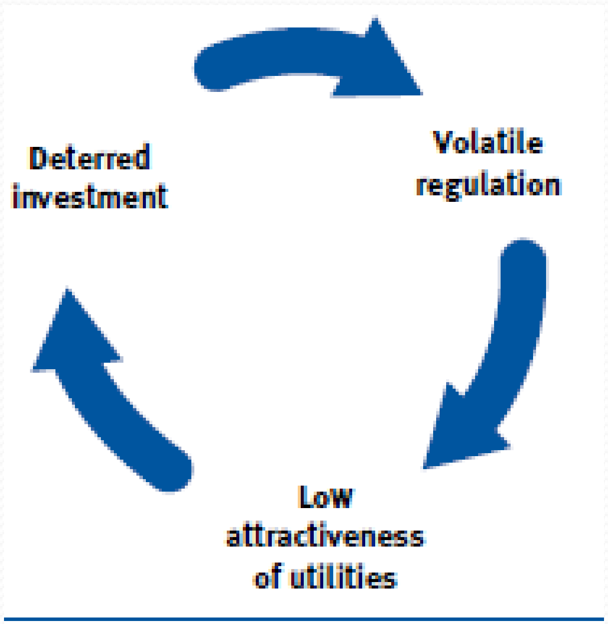
Regulatory Risk:
Experts opinion on Investment Risk



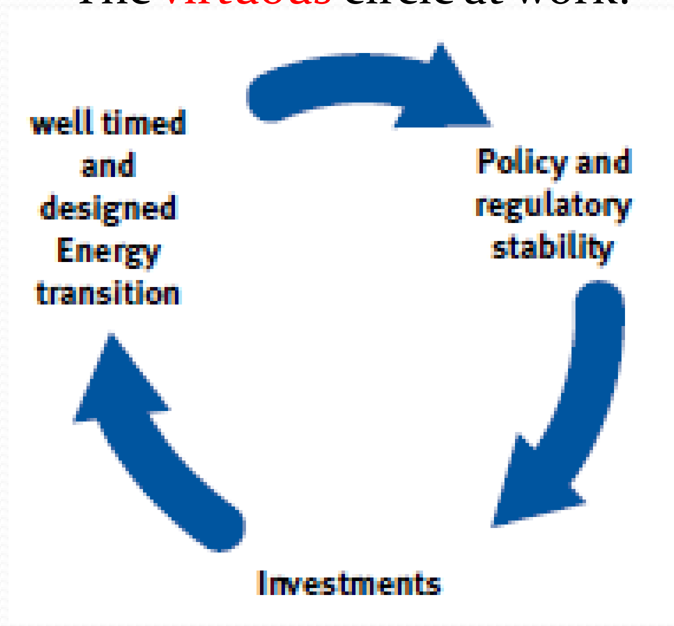
Source: Powering Investments: Challenges for the liberalised electricity sector
Eurelectric Report 2012

Effect of regulation on investments

The vicious circle at work:



The virtuous circle at work:



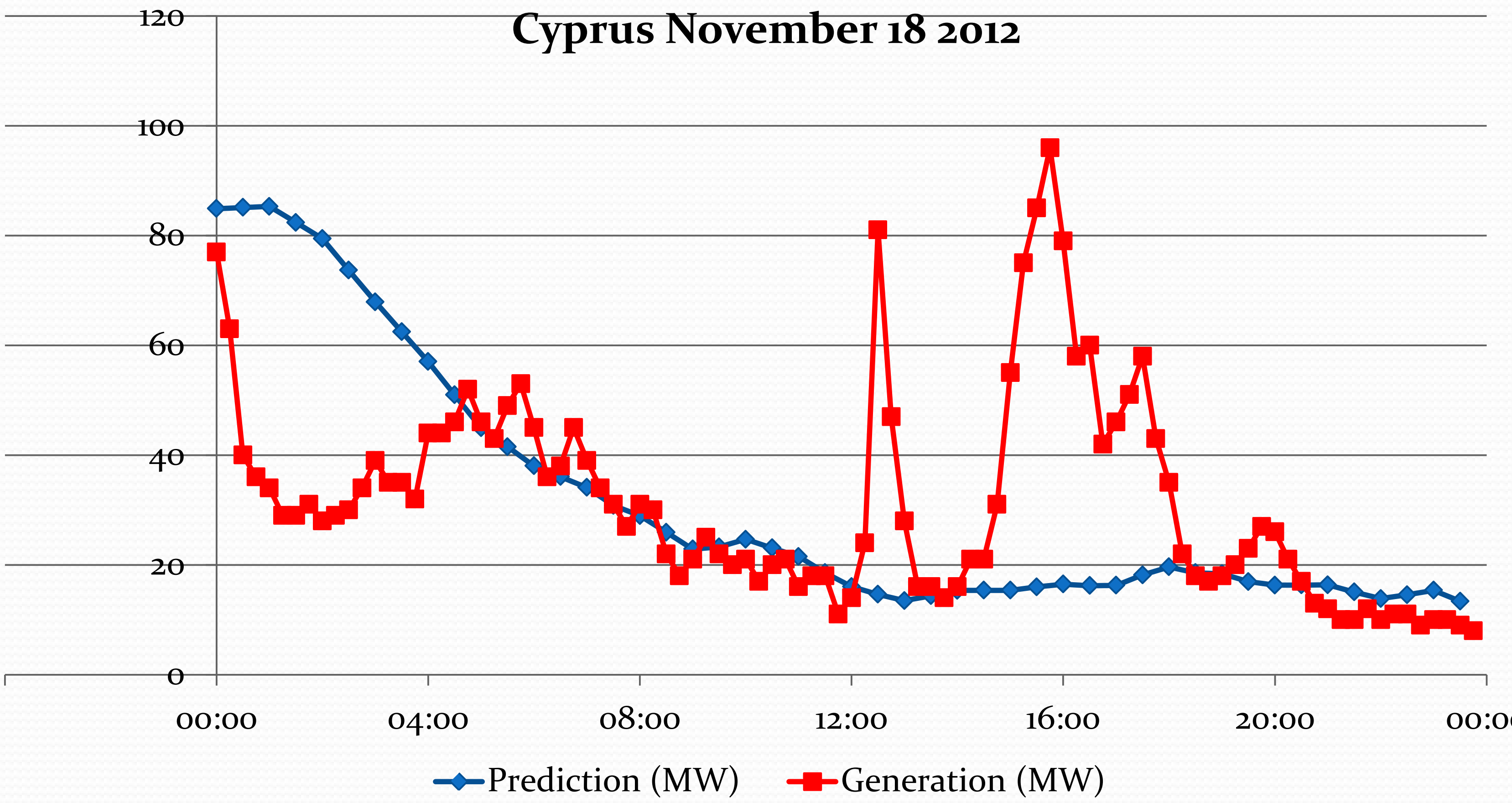
Source: Powering Investments: Challenges for the liberalised electricity sector
Eurelectric Report 2012

Investment Climate in the electricity sector: Europe

- Conventional power generators are expected to
  - Invest in an uncertain environment
  - Generate less energy
  - Accept lower prices for the energy they produce
- The electricity sector is changing fast (partly because of the increased penetration of RESe) while the electricity market has not followed the same pace
- Generators do not have clear <u>market</u> signals for the type of generation required in the future (Capacity? Flexibility? Efficiency?)

Operating the electrical system with Intermittent Generation

RESe Predictions: Wind Generation



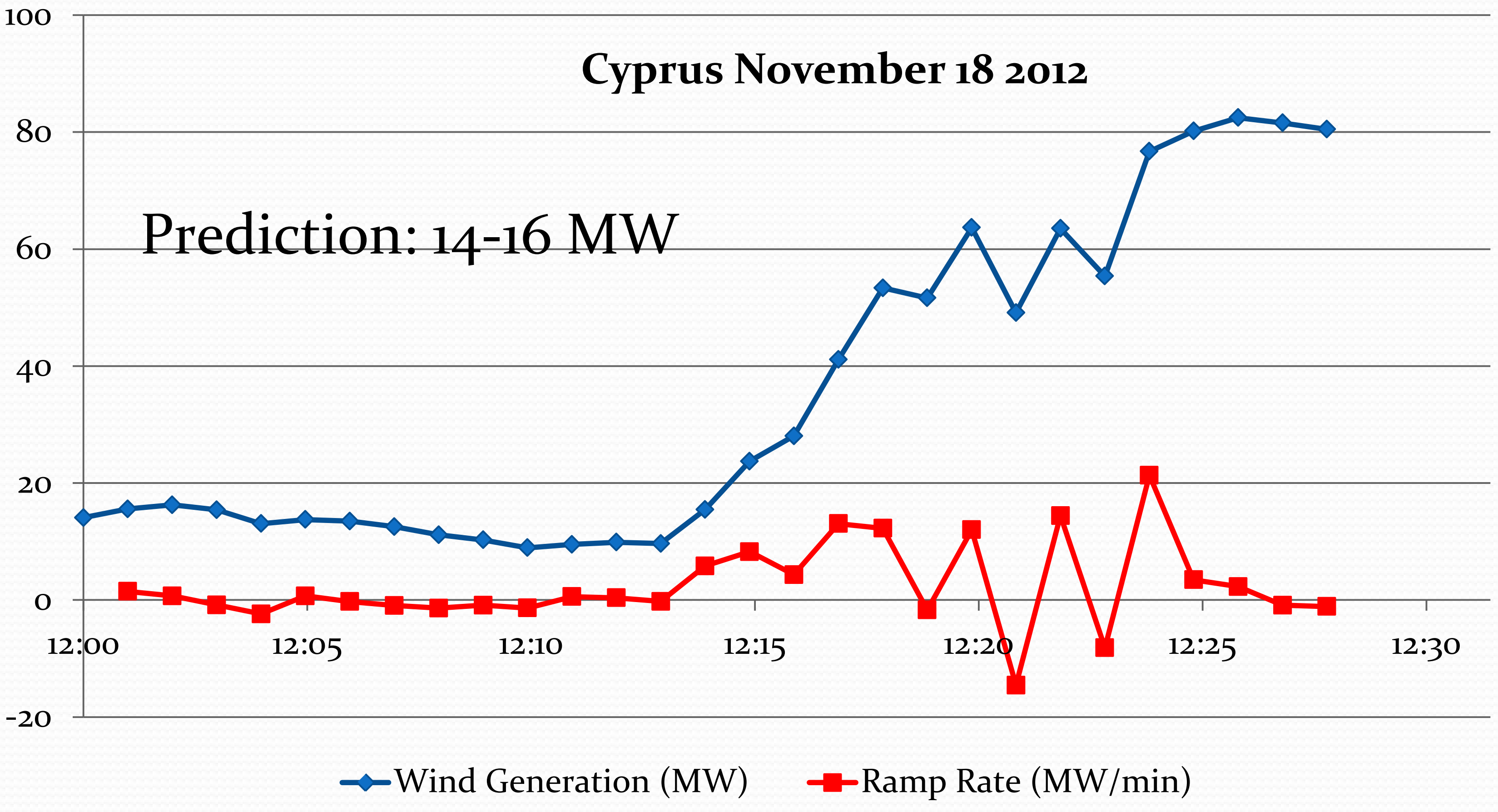
Consequences of bad predictions

- Dispatchable units' commitment is optimised taking into consideration wind generation predictions. Errors in prediction result in sub-optimal scheduling or wind generation curtailment (during low demand periods).
- Dispatched units may not be able to provide adequate fast response (primary and secondary reserve) for high ramp rates in wind generation
- Other ancillary services are also compromised (e.g. reactive power)

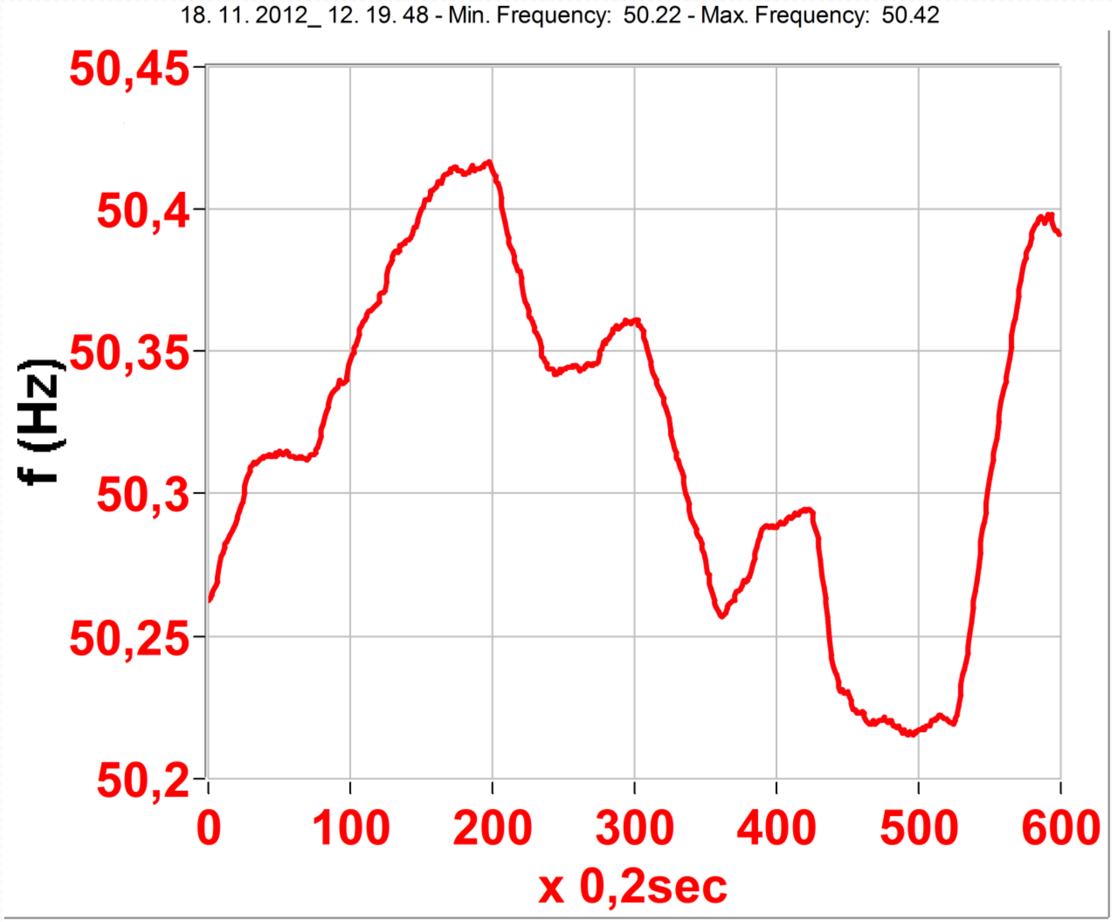
High ramp rates

- Fast increases or decreases in RESe generation are equivalent to loss of generation (ramping down) or loss of demand (ramping up)
- Frequency deviations may result in unacceptable level of frequency if committed units cannot provide the fast response required
- Thermal stresses and excess wear on thermal units due to large and frequent load changes
- The problem is important for small, isolated systems

Case Study: Cyprus, November 18 2012



Frequency Deviation



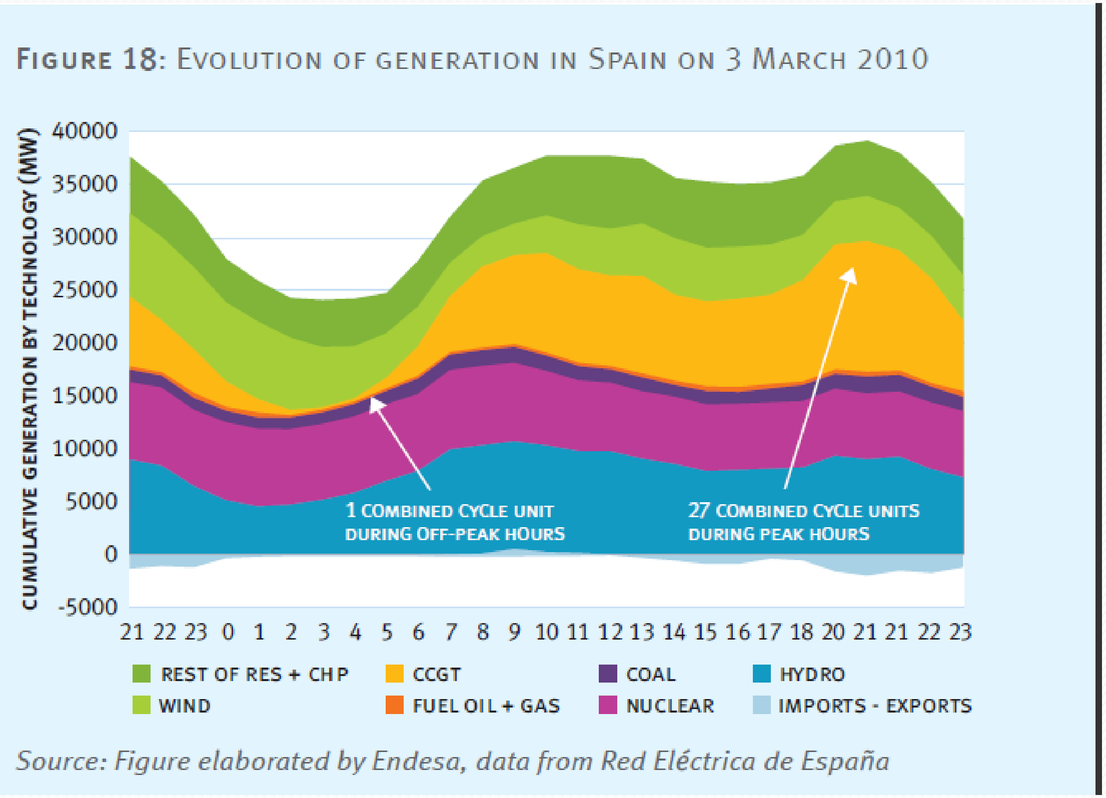
High Ramp Rates: Solutions

- Improvement of RESe predictions
- Fast-responding dispatchable units
- Geographical distribution of wind generation
- Curtailment schemes for high upward ramp rates
- Inertia devices to offer primary and secondary reserve

High intermittent RESe generation during low demand periods

- Thermal units have operational constraints:
  - Minimum stable generation
  - Minimum down time
  - Start-up time
- Shutting down thermal units to absorb 100% of the RESe generation may result in
  - Instability, due to the reduced number of dispatchable units committed (limits ancillary services)
  - Increased cost (and perhaps increased environmental cost) due to the start-up cost and non-availability of base load units to cover increased demand later on

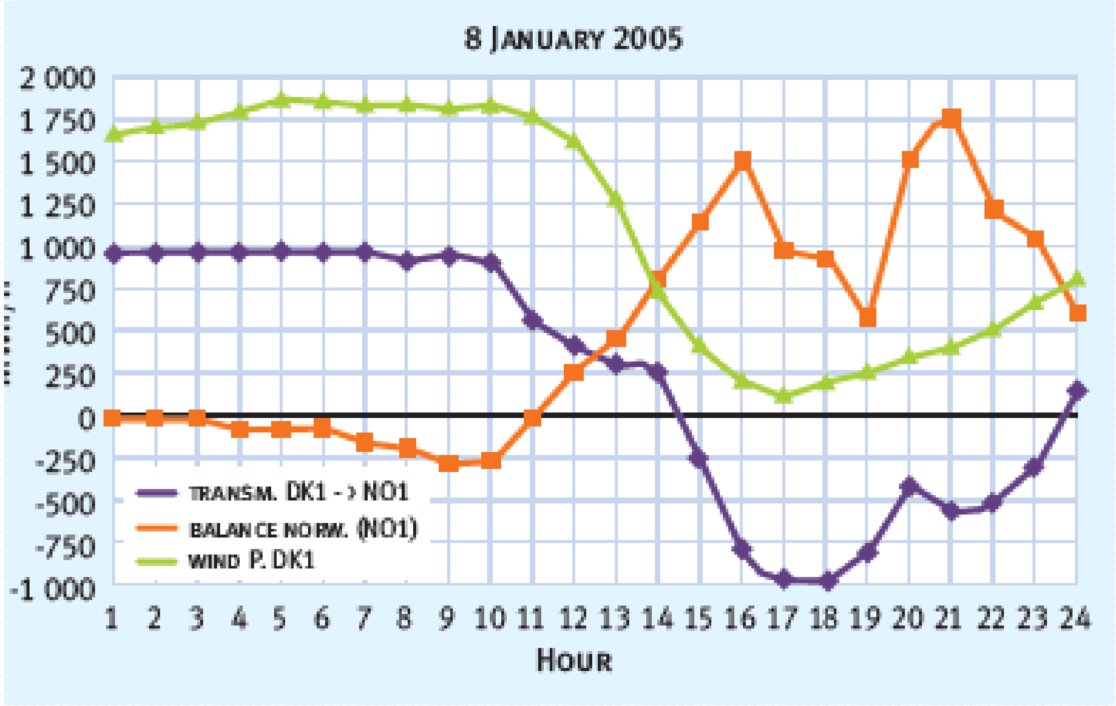
Flexibility in dispatchable generation: Spain



Source: Flexible generation: Backing up renewables

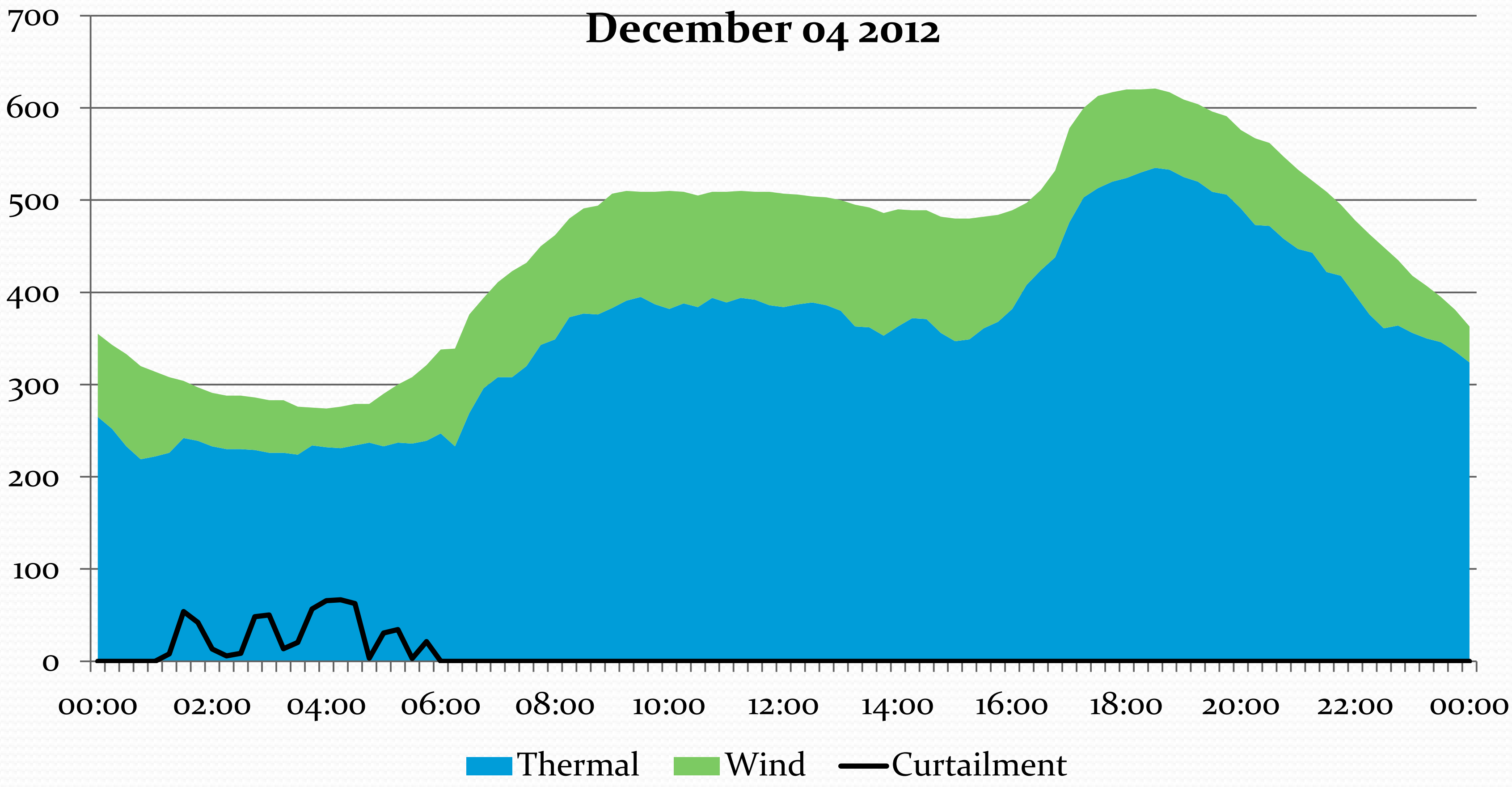
Eurelectric Report 2011

Flexibility in dispatchable generation: Nordic system

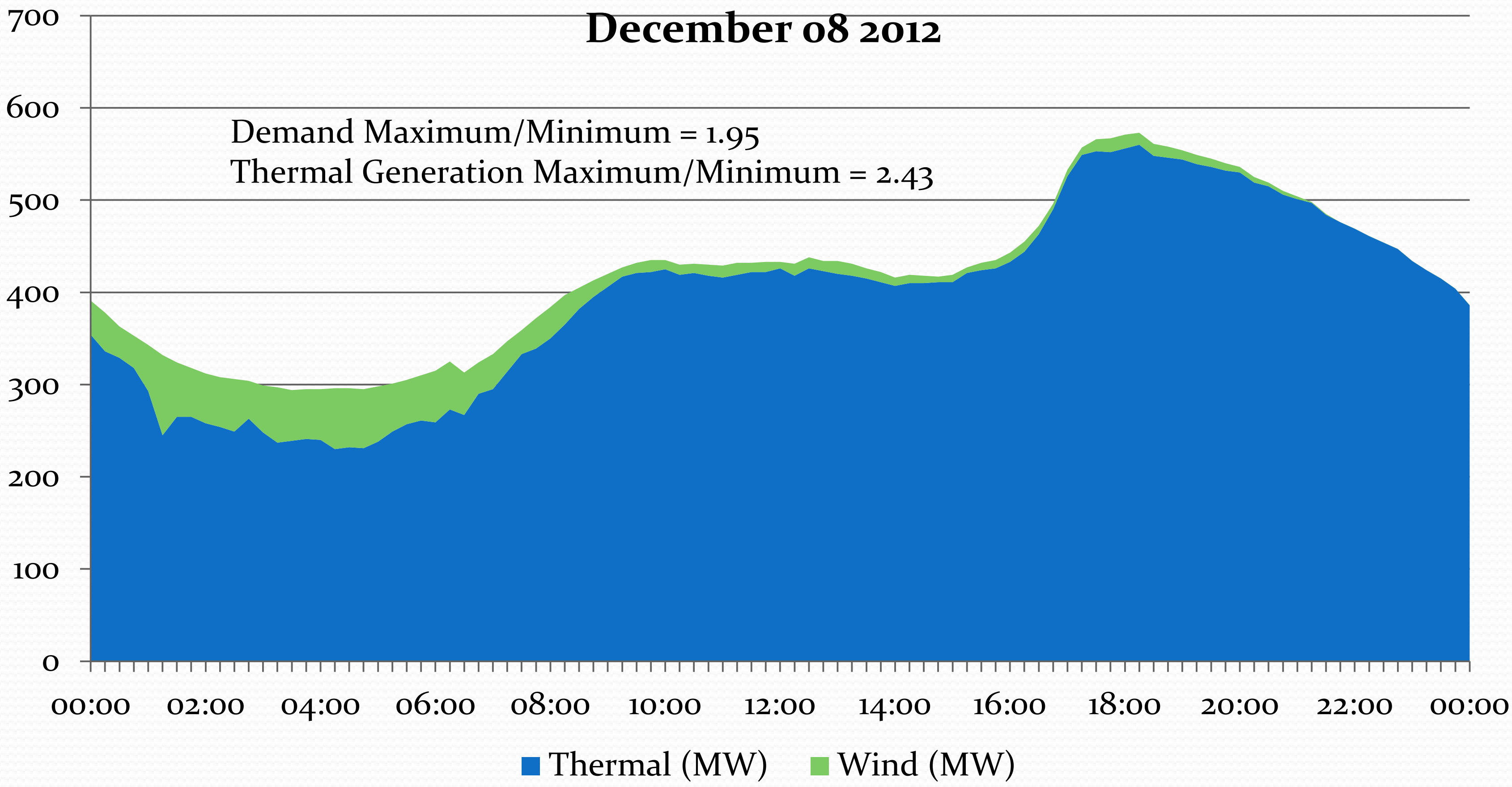


Source: Flexible generation: Backing up renewables
Eurelectric Report 2011

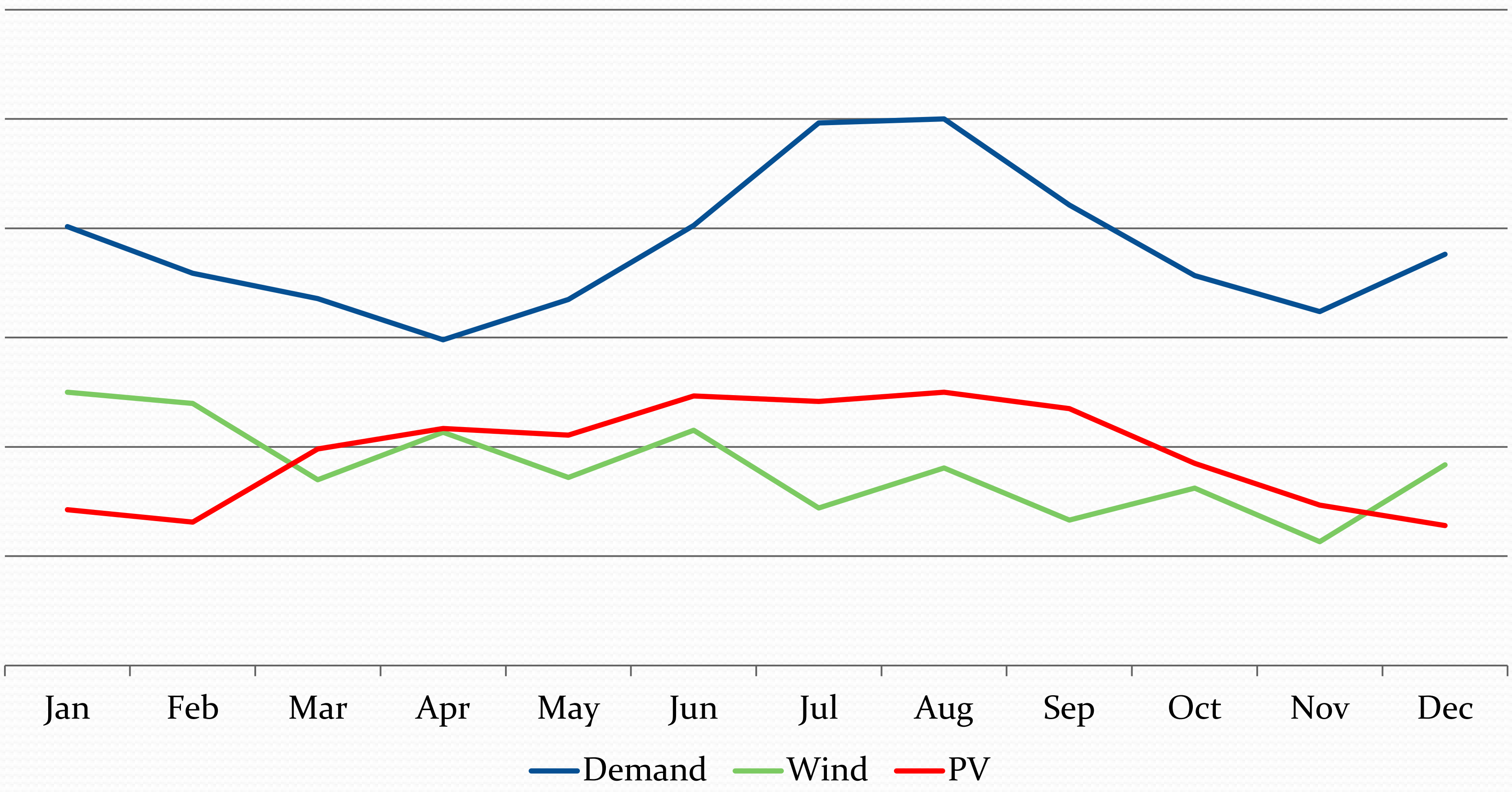
Wind Generation During Low Demand (Cyprus): Curtailment



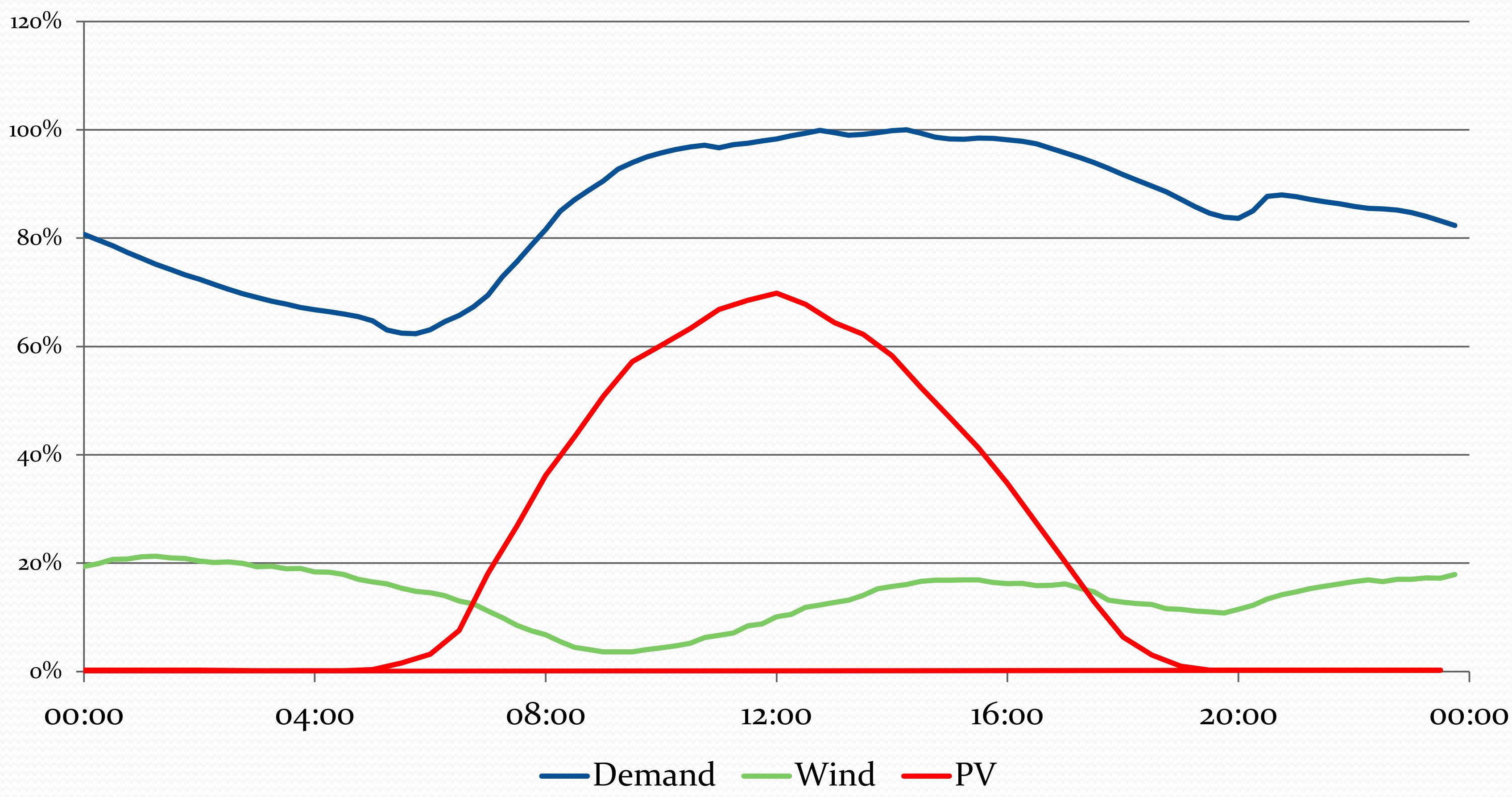
Wind Generation During Low Demand (Cyprus): Flexibility requirements



Wind vs. Photovoltaics:
Monthly Energy Generation, Cyprus



Wind vs. Photovoltaics: July Daily Load Factor, Cyprus



High RESe generation during low demand periods: Solutions

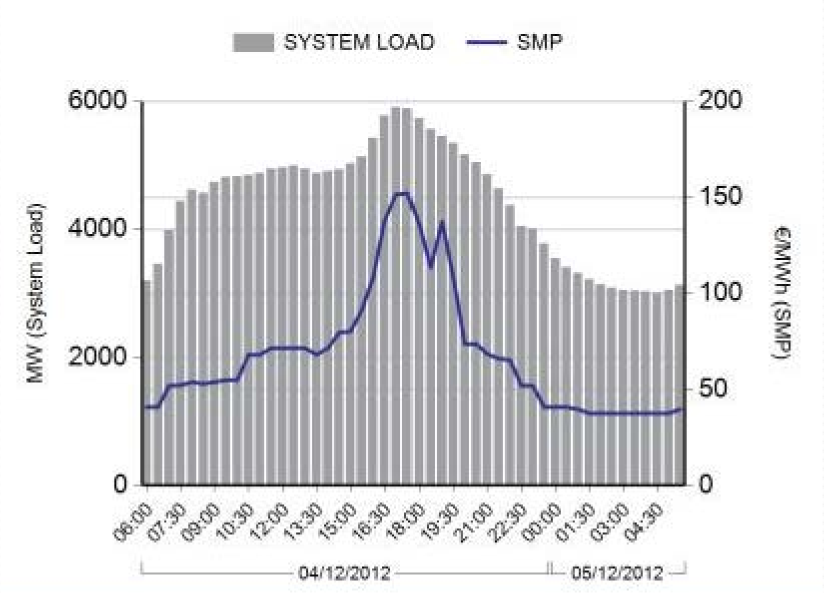
- RESe curtailment
- Enlarge the electrical system – transmission interconnections
- Energy Storage
  - Pumped storage, compressed air storage
  - Batteries
  - Hydrogen
- Flexible generation: Start/stop capability, favourable maximum/minimum load
  - Hydropower
  - Diesel engines
  - Gas turbines
- Demand-side management
  - Incentives to consumers to consume more during the night and less during the day (smart meters, price signals)
- Incentivise RESe with favourable generation profiles

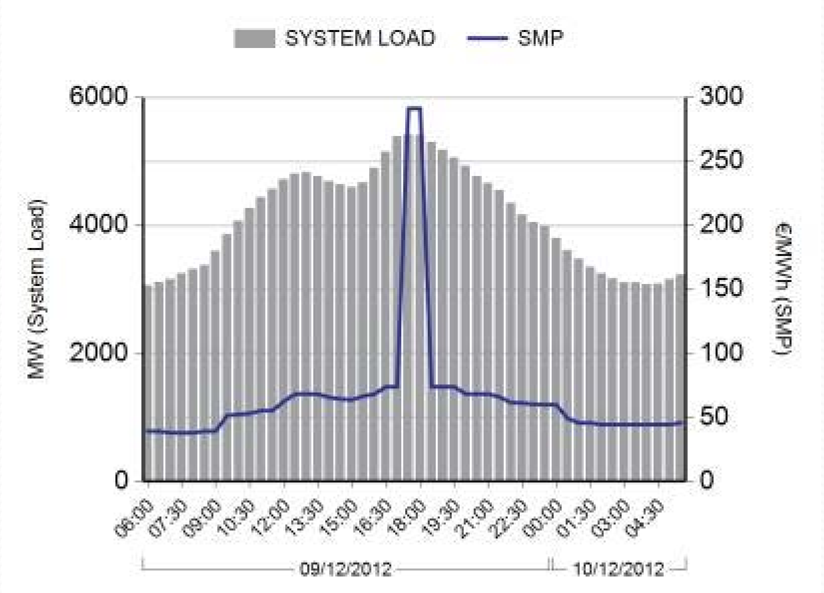
Not all Renewables are created equal…

<table>
<tr><th>RES technology</th><th>Energy Profile</th><th>Capacity Contribution</th><th>Operating Reserve</th><th>Voltage Control</th></tr>
<tr><td>Wind</td><td>Uniform</td><td>Extremely low (zero)</td><td>Some, with energy withholding</td><td>Yes</td></tr>
<tr><td>Photovoltaics</td><td rowspan="2">Favourable, especially for systems with peak demand in the summer</td><td>Partial, depending on configuration (tracking) and system demand profile</td><td>No</td><td>No</td></tr>
<tr><td>Solar Thermal</td><td>Partial, depending on system demand profile</td><td>Yes, increased with storage</td><td>Yes</td></tr>
<tr><td>Hydroelectric</td><td>Dispatchable</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Biomass</td><td>Usually flat, but dispatchable</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
</table>

Market and Regulatory Issues

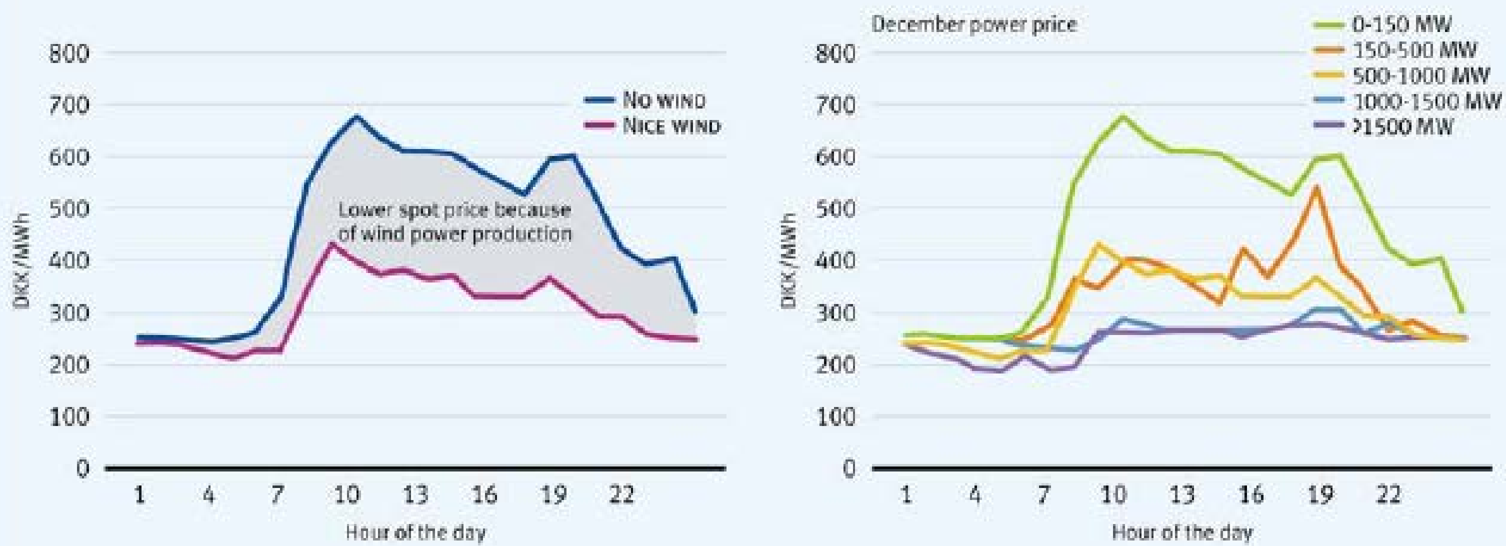
Marginal price of electricity
Ireland 04/12/2012, 08/12/2012





Effect of RESe on market prices:
West Denmark

FIGURE S.13: THE IMPACT OF WIND POWER ON THE SPOT POWER PRICE IN THE WEST DENMARK POWER SYSTEM IN DECEMBER 2005



Source: Risø DTU

Source: Flexible generation: Backing up renewables
Eurelectric Report 2011

Capacity

- RESe contribute only a portion of their installed capacity towards generation adequacy
- Other firm capacity is required to close the gap. Investment in RESe reduces the need for investment in conventional generation only partially
- As load factors of conventional generation are reduced, investors are unwilling to build new plants
- Incentives are required to build new investments
- Compensation for capacity should be considered

Market Integration of Renewables

- Feed-in tariffs most popular incentive scheme today
- Good to kick-start investments in RESe (low-risk investment) but not linked to electricity markets
- Other incentive schemes, such as feed-in premiums, should be considered for the gradual integration or RESe to the market
- Participation of RES in the ancillary and capacity markets
- Capacity remuneration mechanisms (CRMs) should be considered to incentivise investments in back-up generation

Feed-in premiums: RESe receives a premium above market price

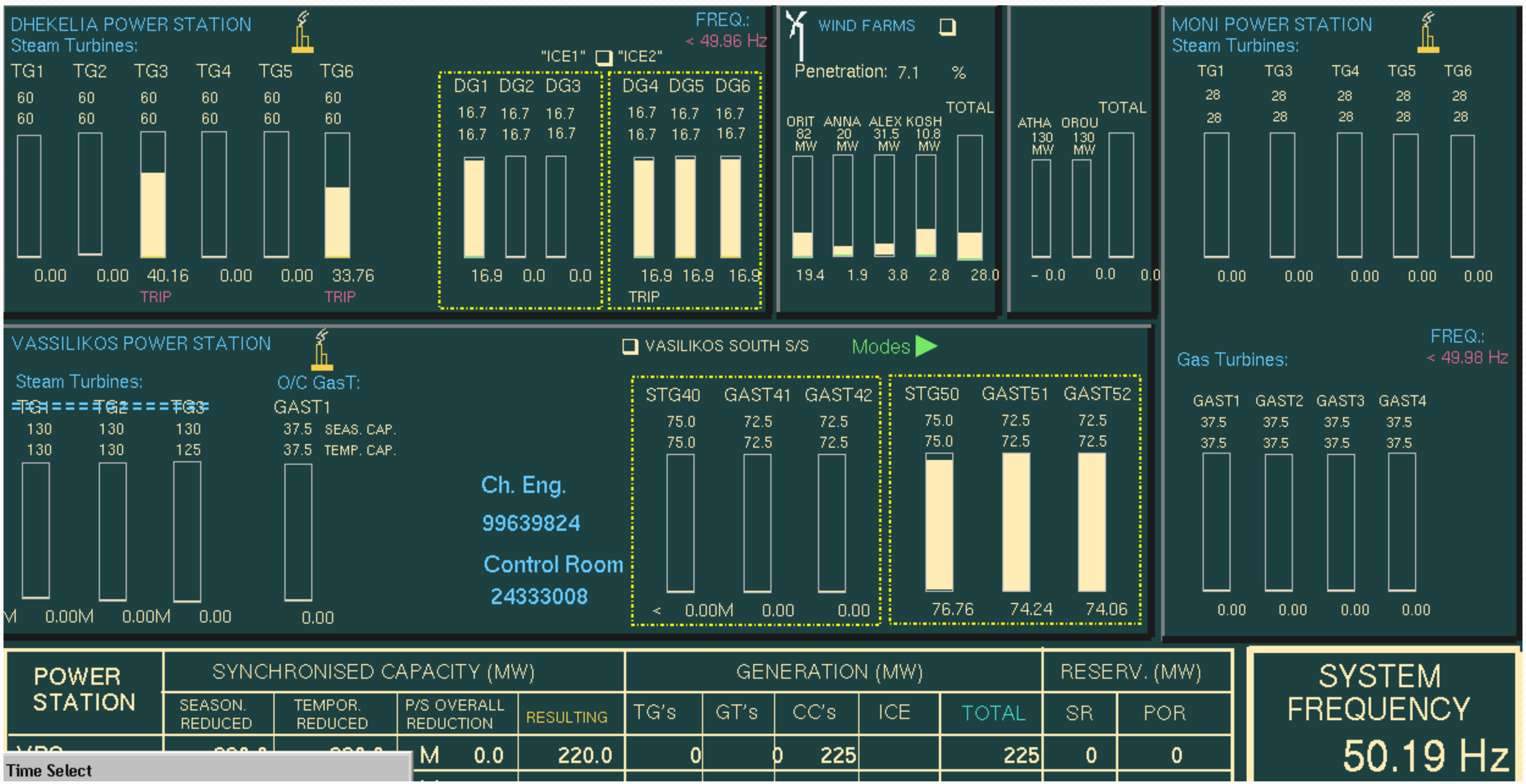
Conclusions (1)

- RESe have an important role to play in the energy and electricity future
- A comprehensive, coherent environmental and energy policy is required
- Look at the electrical system as a whole – not just renewables
- A stable investment climate must be cultivated for conventional generation
- Operational problems can be eased by
  - Proper planning and design of RESe policy
  - Proper market design to recognise the changing needs of the system
- RESe penetration is fast, market reform is lagging behind.
- RESe must be gradually integrated into the market.

Conclusions (2)

- Capacity compensation schemes should be considered, where appropriate, as an interim solution
- Differences in RESe generation profiles, ancillary service contribution and capacity contribution must be recognised (and remunerated)
- Best solution for all does not exist. Regional differences must be recognised. For example, solar energy offers advantages over wind generation for Cyprus
- Energy storage has an important role to play
- European (or regional) market integration must move forward. Transmission highways must open

Cyprus System 18/11/2012 12:16



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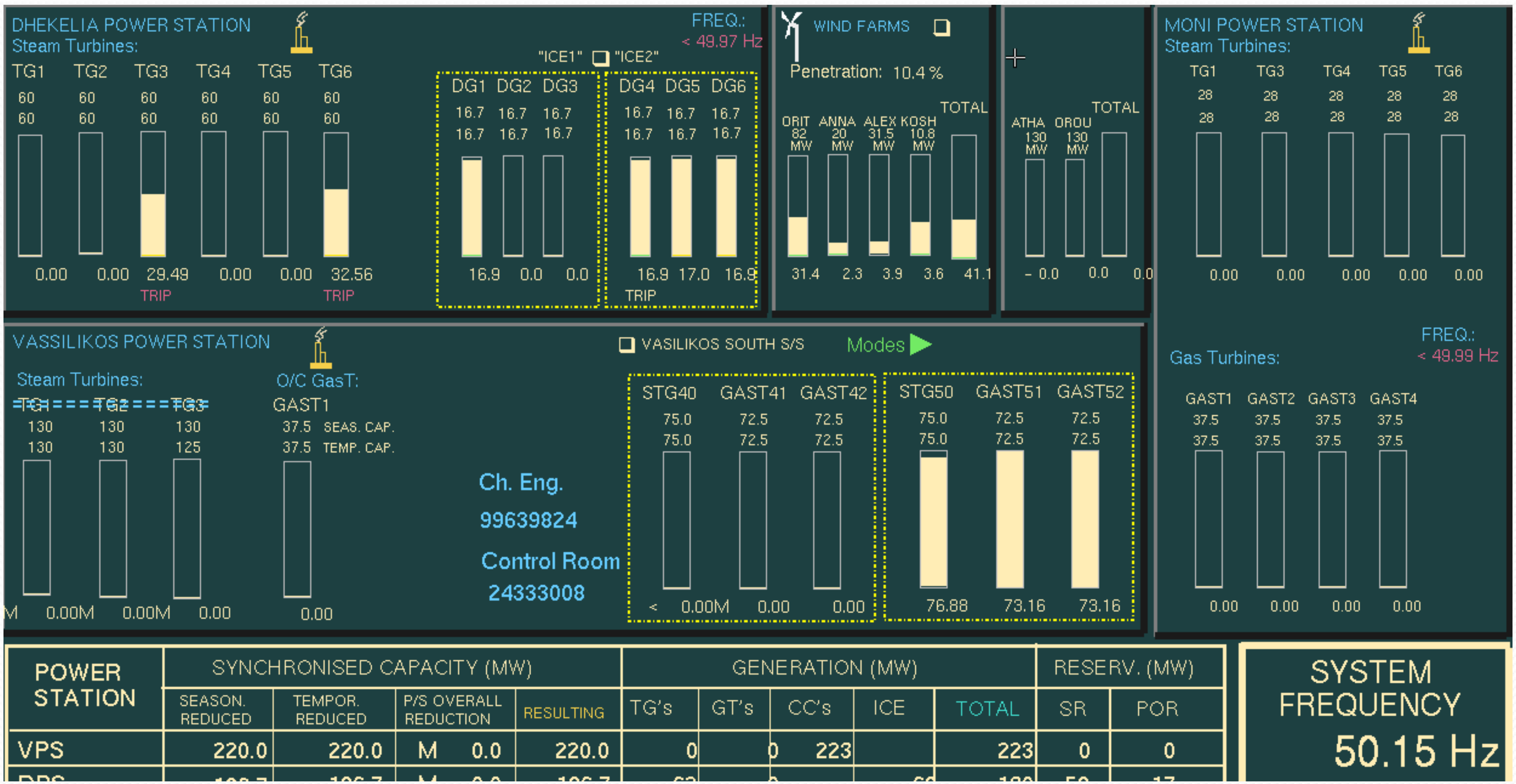
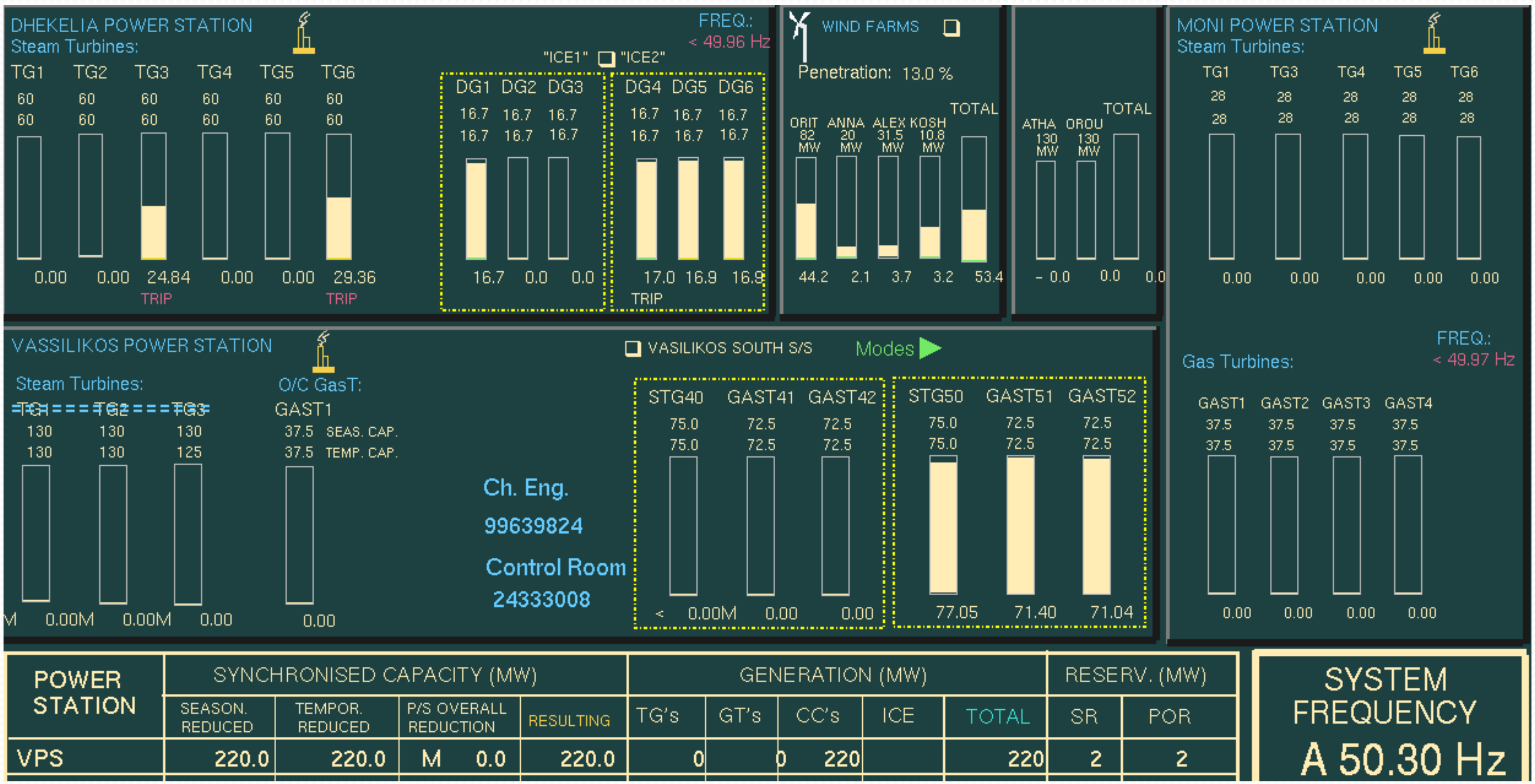


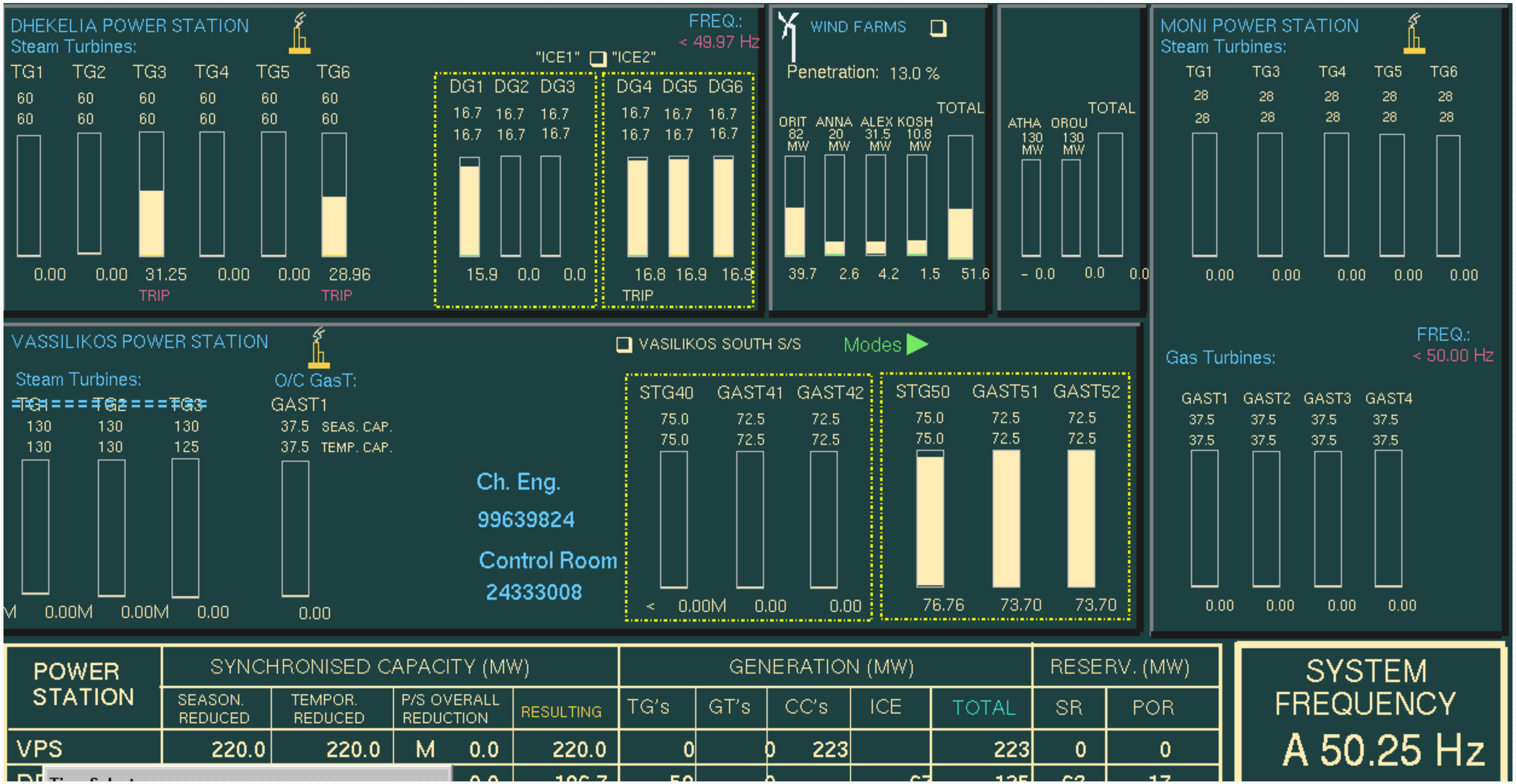
DHEKELIA POWER STATION
Steam Turbines:
FREQ.:
< 49.97 Hz
"ICE1" "ICE2"
TG1 TG2 TG3 TG4 TG5 TG6
0.00 0.00 29.49 0.00 0.00 32.56
TRIP TRIP
DG1 DG2 DG3
16.9 0.0 0.0
DG4 DG5 DG6
16.9 17.0 16.8
TRIP
WIND FARMS
Penetration: 10.4 %
TOTAL
ORIT ANNA ALEX KOSH
31.4 2.3 3.9 3.6 41.1
ATHA OROU
TOTAL
MONI POWER STATION
Steam Turbines:
TG1 TG3 TG4 TG5 TG6
Gas Turbines:
FREQ.:
< 49.99 Hz
GAST1 GAST2 GAST3 GAST4
VASSILIKOS POWER STATION
Steam Turbines:
O/C GasT:
GAST1
SEAS. CAP.
TEMP. CAP.
VASILIKOS SOUTH S/S
Modes
STG40 GAST41 GAST42
STG50 GAST51 GAST52
76.88 73.16 73.16
Ch. Eng.
99639824
Control Room
24333008
POWER STATION
SYNCHRONISED CAPACITY (MW)
SEASON. REDUCED
TEMPOR. REDUCED
P/S OVERALL REDUCTION
RESULTING
GENERATION (MW)
TG's GT's CC's ICE TOTAL
RESERV. (MW)
SR POR
VPS 220.0 220.0 M 0.0 220.0 0 0 223 223 0 0
SYSTEM FREQUENCY
50.15 Hz

12:18



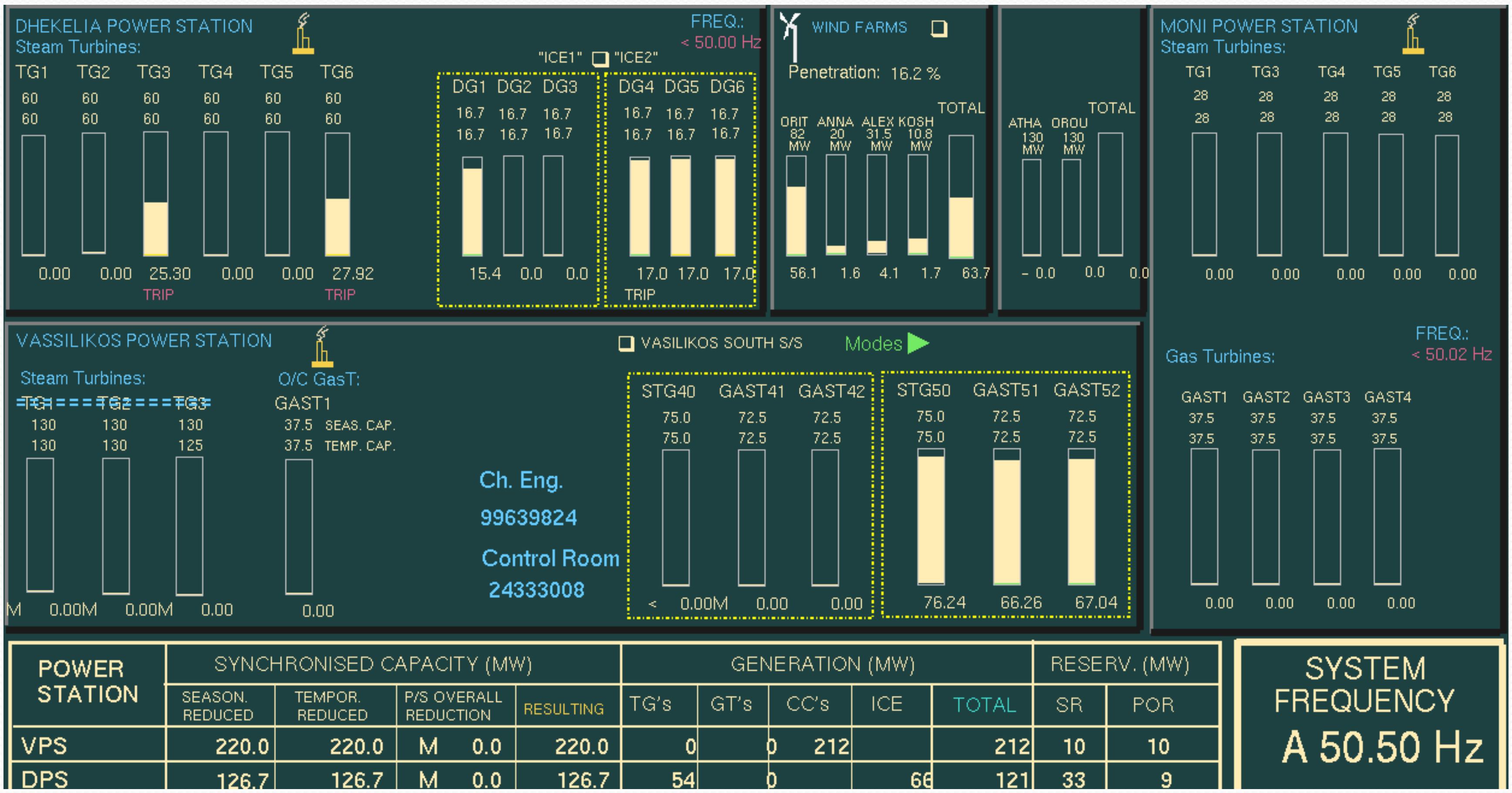
DHEKELIA POWER STATION
Steam Turbines:
TG1 TG2 TG3 TG4 TG5 TG6
60 60 60 60 60 60
60 60 60 60 60 60
0.00 0.00 24.84 0.00 0.00 29.36
TRIP TRIP
FREQ.:
< 49.96 Hz
"ICE1" "ICE2"
DG1 DG2 DG3
16.7 16.7 16.7
16.7 16.7 16.7
16.7 0.0 0.0
DG4 DG5 DG6
16.7 16.7 16.7
16.7 16.7 16.7
17.0 16.9 16.9
TRIP
WIND FARMS
Penetration: 13.0 %
ORIT 82 MW ANNA 20 MW ALEX 31.5 MW KOSH 10.8 MW TOTAL
44.2 2.1 3.7 3.2 53.4
ATHA 130 MW OROU 130 MW TOTAL
- 0.0 0.0 0.0
MONI POWER STATION
Steam Turbines:
TG1 TG3 TG4 TG5 TG6
28 28 28 28 28
28 28 28 28 28
0.00 0.00 0.00 0.00 0.00
Gas Turbines:
FREQ.:
< 49.97 Hz
GAST1 GAST2 GAST3 GAST4
37.5 37.5 37.5 37.5
37.5 37.5 37.5 37.5
0.00 0.00 0.00 0.00
VASSILIKOS POWER STATION
Steam Turbines:
TG1 TG2 TG3
130 130 130
130 130 125
M 0.00M 0.00M 0.00
O/C GasT:
GAST1
37.5 SEAS. CAP.
37.5 TEMP. CAP.
0.00
Ch. Eng.
99639824
Control Room
24333008
VASILIKOS SOUTH S/S
Modes
STG40 GAST41 GAST42
75.0 72.5 72.5
75.0 72.5 72.5
< 0.00M 0.00 0.00
STG50 GAST51 GAST52
75.0 72.5 72.5
75.0 72.5 72.5
77.05 71.40 71.04
POWER STATION
SYNCHRONISED CAPACITY (MW)
SEASON. REDUCED
TEMPOR. REDUCED
P/S OVERALL REDUCTION
RESULTING
GENERATION (MW)
TG's GT's CC's ICE TOTAL
RESERV. (MW)
SR POR
VPS 220.0 220.0 M 0.0 220.0 0 0 220 220 2 2
SYSTEM FREQUENCY
A 50.30 Hz

12:19



DHEKELIA POWER STATION
Steam Turbines:
TG1 TG2 TG3 TG4 TG5 TG6
0.00 0.00 31.25 0.00 0.00 28.96
TRIP TRIP
FREQ.:
< 49.97 Hz
"ICE1" "ICE2"
DG1 DG2 DG3
15.9 0.0 0.0
DG4 DG5 DG6
16.8 16.9 16.9
TRIP
WIND FARMS
Penetration: 13.0 %
ORIT ANNA ALEX KOSH TOTAL
39.7 2.6 4.2 1.5 51.6
ATHA OROU TOTAL
MONI POWER STATION
Steam Turbines:
TG1 TG3 TG4 TG5 TG6
Gas Turbines:
GAST1 GAST2 GAST3 GAST4
FREQ.:
< 50.00 Hz
VASSILIKOS POWER STATION
Steam Turbines:
O/C GasT:
GAST1
SEAS. CAP.
TEMP. CAP.
VASILIKOS SOUTH S/S
Modes
STG40 GAST41 GAST42
STG50 GAST51 GAST52
76.76 73.70 73.70
Ch. Eng.
99639824
Control Room
24333008
POWER STATION
SYNCHRONISED CAPACITY (MW)
SEASON. REDUCED
TEMPOR. REDUCED
P/S OVERALL REDUCTION
RESULTING
GENERATION (MW)
TG's GT's CC's ICE TOTAL
RESERV. (MW)
SR POR
VPS 220.0 220.0 M 0.0 220.0 0 0 223 223 0 0
SYSTEM FREQUENCY
A 50.25 Hz

12:20


DHEKELIA POWER STATION
Steam Turbines:
TG1 TG2 TG3 TG4 TG5 TG6
0.00 0.00 25.30 0.00 0.00 27.92
TRIP TRIP
FREQ.:
< 50.00 Hz
"ICE1" "ICE2"
DG1 DG2 DG3
15.4 0.0 0.0
DG4 DG5 DG6
17.0 17.0 17.0
TRIP
WIND FARMS
Penetration: 16.2 %
ORIT 82 MW ANNA 20 MW ALEX 31.5 MW KOSH 10.8 MW TOTAL
56.1 1.6 4.1 1.7 63.7
ATHA 130 MW OROU 130 MW TOTAL
- 0.0 0.0 0.0
MONI POWER STATION
Steam Turbines:
TG1 TG3 TG4 TG5 TG6
0.00 0.00 0.00 0.00 0.00
Gas Turbines:
FREQ.:
< 50.02 Hz
GAST1 GAST2 GAST3 GAST4
0.00 0.00 0.00 0.00
VASSILIKOS POWER STATION
Steam Turbines:
TG1 TG2 TG3
0.00M 0.00M 0.00
O/C GasT:
GAST1
SEAS. CAP.
TEMP. CAP.
0.00
VASILIKOS SOUTH S/S
Modes
Ch. Eng.
99639824
Control Room
24333008
STG40 GAST41 GAST42
0.00M 0.00 0.00
STG50 GAST51 GAST52
76.24 66.26 67.04
POWER STATION
SYNCHRONISED CAPACITY (MW)
SEASON. REDUCED
TEMPOR. REDUCED
P/S OVERALL REDUCTION
RESULTING
GENERATION (MW)
TG's GT's CC's ICE TOTAL
RESERV. (MW)
SR POR
VPS 220.0 220.0 M 0.0 220.0 0 0 212 212 10 10
DPS 126.7 126.7 M 0.0 126.7 54 0 66 121 33 9
SYSTEM FREQUENCY
A 50.50 Hz

Market Challenges

- Imagine an electrical system with 80%-100% RESe penetration
- Energy balance is achieved through storage (large scale and/or distributed)
- Operating reserve provided by RESe, large scale energy storage facilities, demand side management, conventional generation.

- Questions:
  1. What is the price of electricity (marginal price)?
  2. Who pays for back-up generation capacity and/or storage?