Power System Balancing with High Renewable Penetration: The Potential of Demand Response

by

D. Karl Critz

Submitted to the Engineering Systems Division
in partial fulfillment of the requirements for the degree of

Master of Science in Management and Engineering
at the
Massachusetts Institute of Technology

“Paying People to Turn Off Their Appliances When the Wind Stops Blowing”

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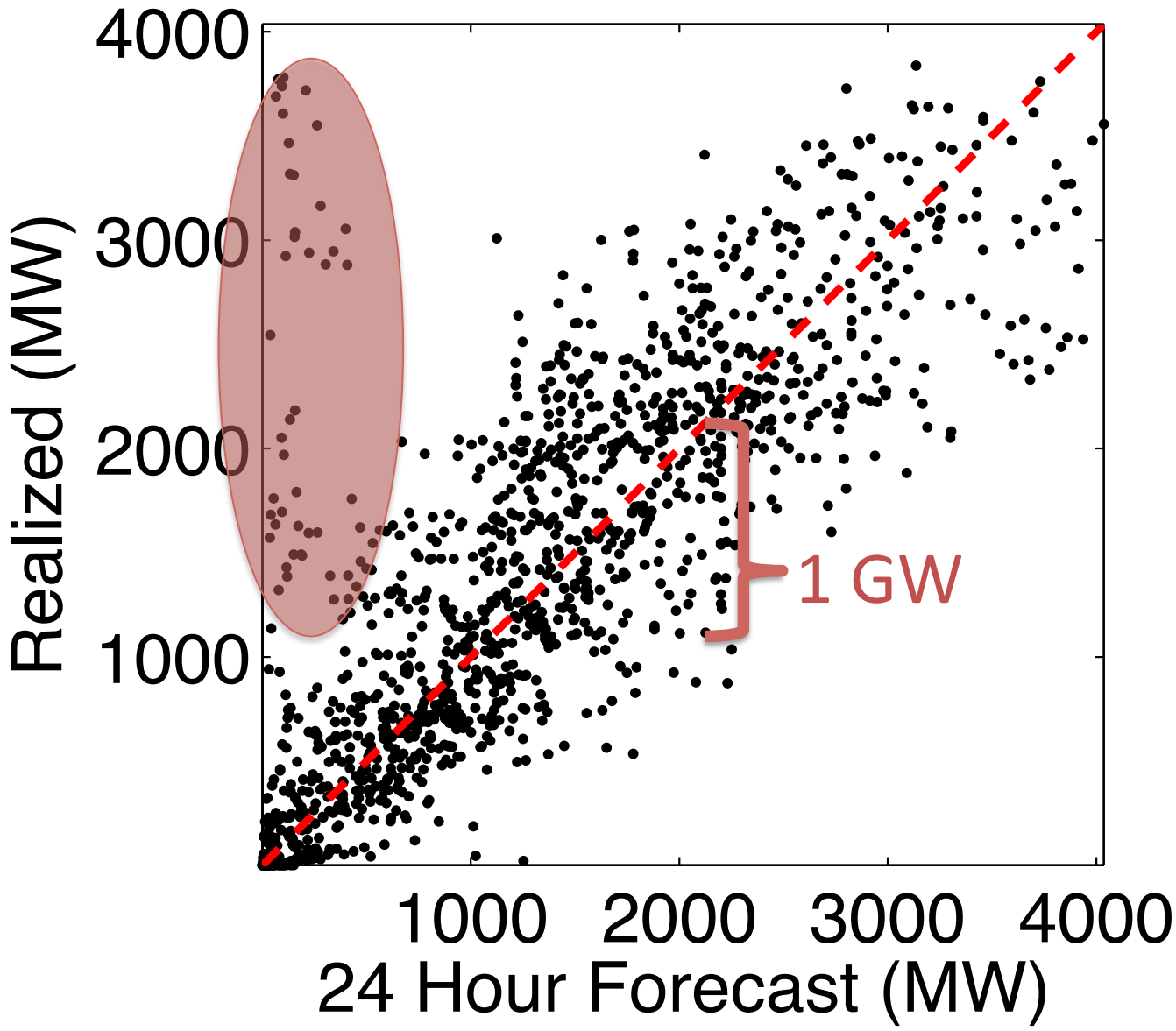
DANMARK

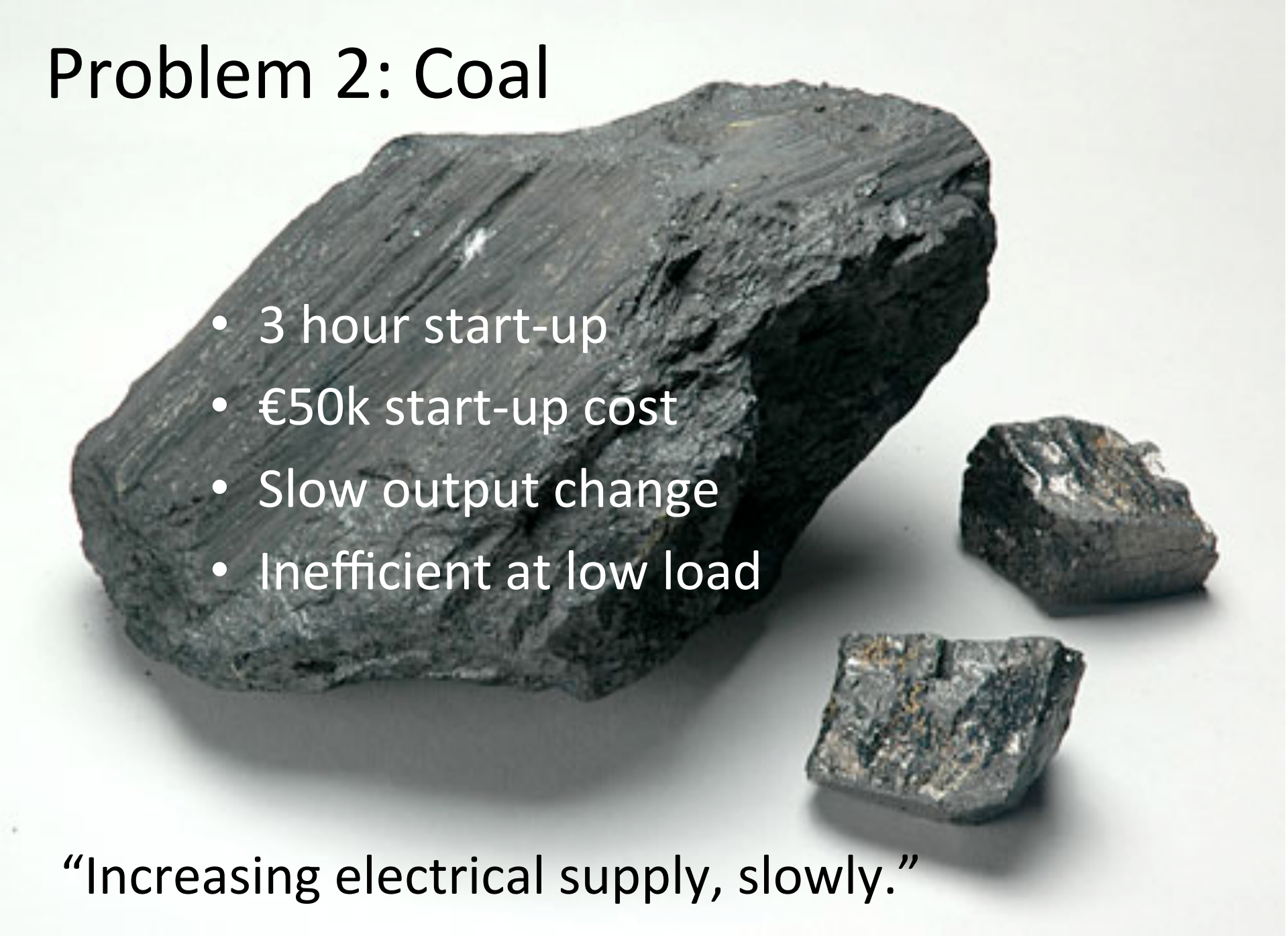

Copenhagen, Denmark
travelblog.org
HAVFRUEN


50% wind
energy by
2025

Problem 1: Wind Forecast Error



Problem 2: Coal



- 3 hour start-up
- €50k start-up cost
- Slow output change
- Inefficient at low load

"Increasing electrical supply, slowly."

Source: Bolton Science Museum

Traditional Solution: Natural Gas

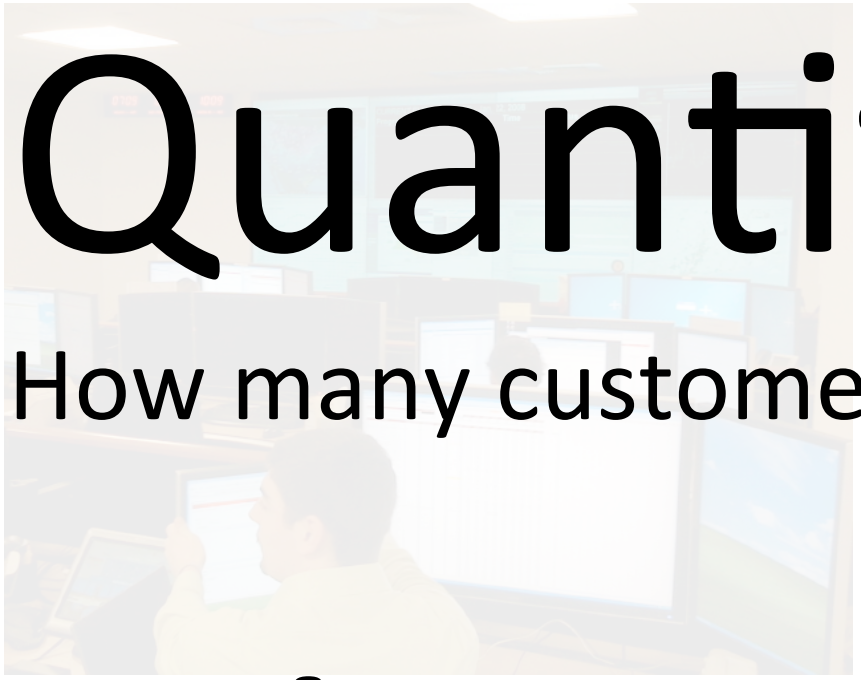
Source: Energy Industry Photos

- 1 hr start-up
- €25k start-up cost
- Fast output change

- High capital cost

"Increasing electrical supply, quickly."

New Solution: Demand Response



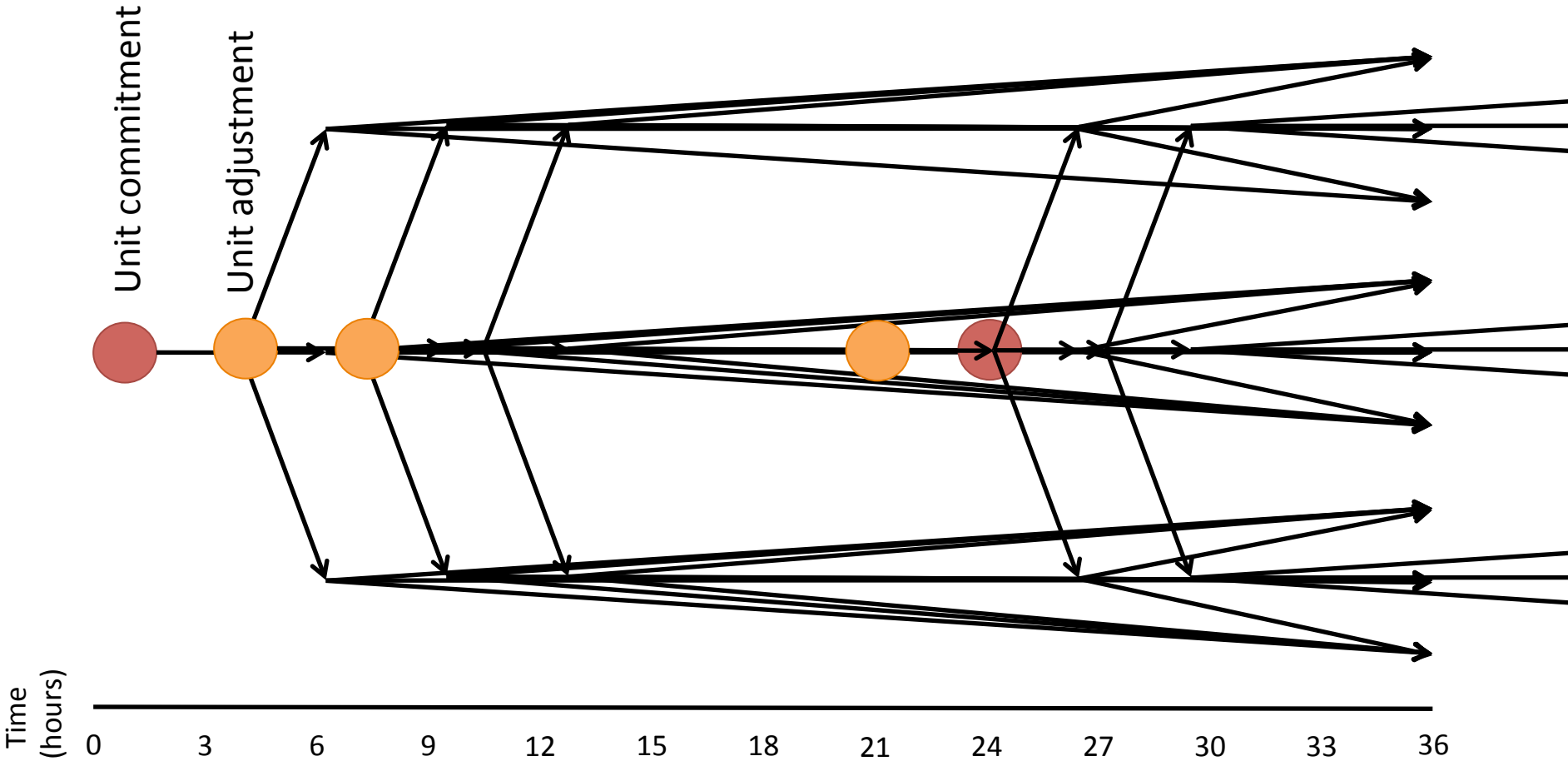
Quantity:

How many customers do you sign up?

Price:

How much are participants paid?

Stochastic Optimization
Rolling Unit Commitment



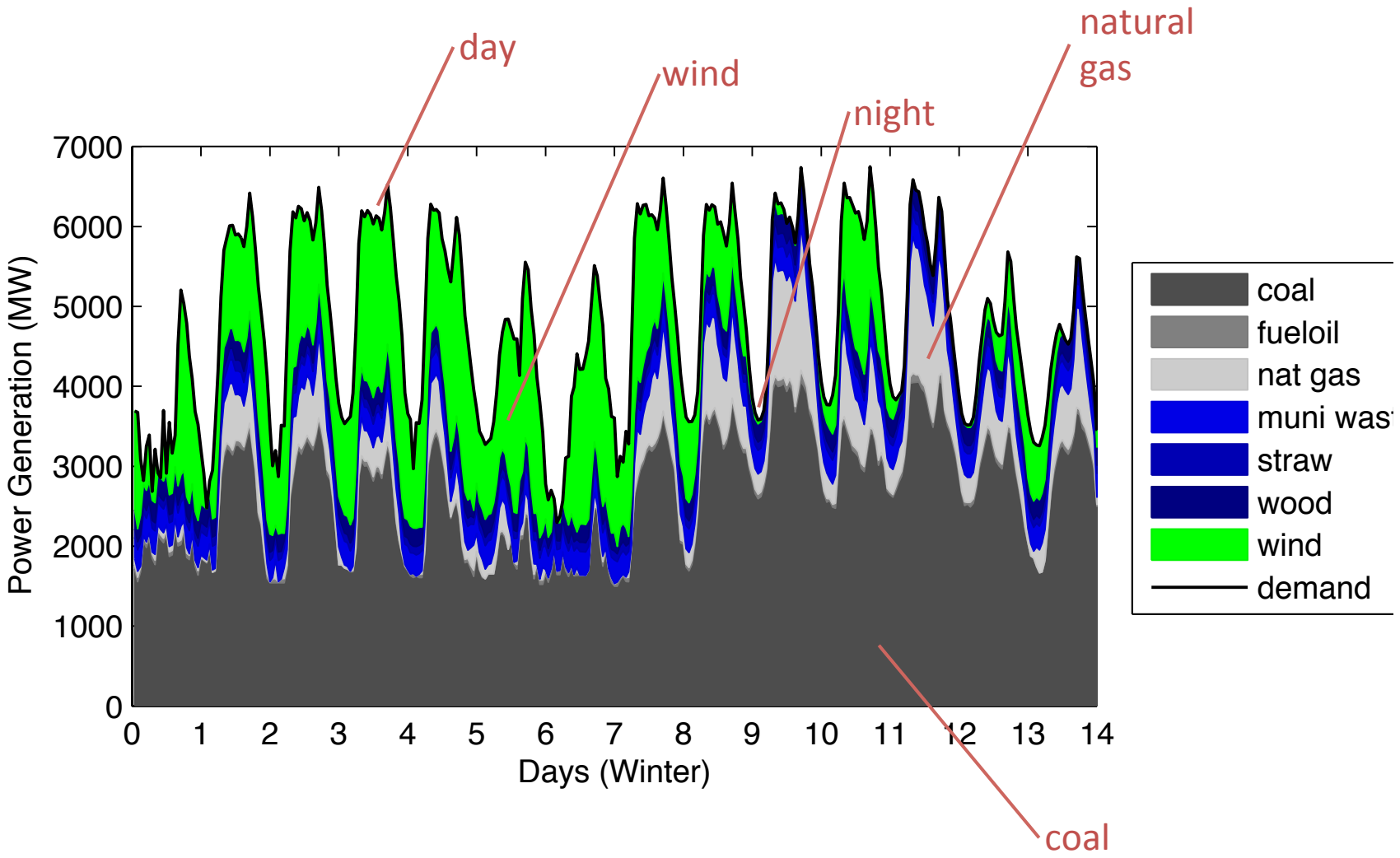
WILMAR Model

- Developed by RISØ

Technical University of Denmark

- Systems studied:
  - Nordic countries + Germany
  - Ireland
  - Spain
  - US (Eastern Interconnect)
- System cost savings 1-3%

Simulate The System



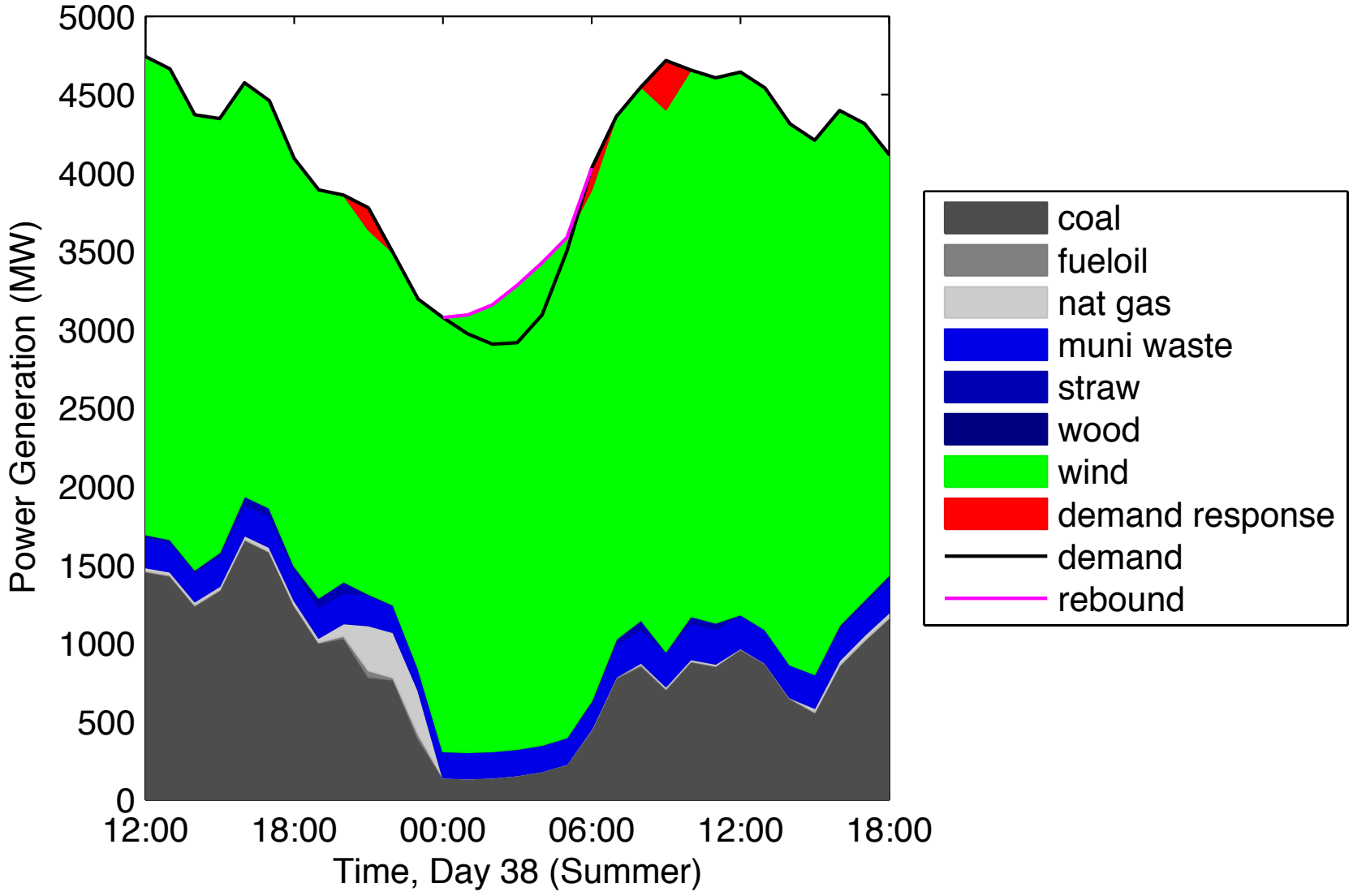
Modeling Demand Response

Property	Value	Unit
Bid price	30-80	€/MWh (gas=40)
Installed base	210-8200	MW (wind=4100)
Rebound effect	5	%
Max duration	2	hr (per customer)
Min duration	0	hr
Max frequency	1	event/day (per customer)
Lead time	0 (fast-DR) 3 (slow-DR)	hr

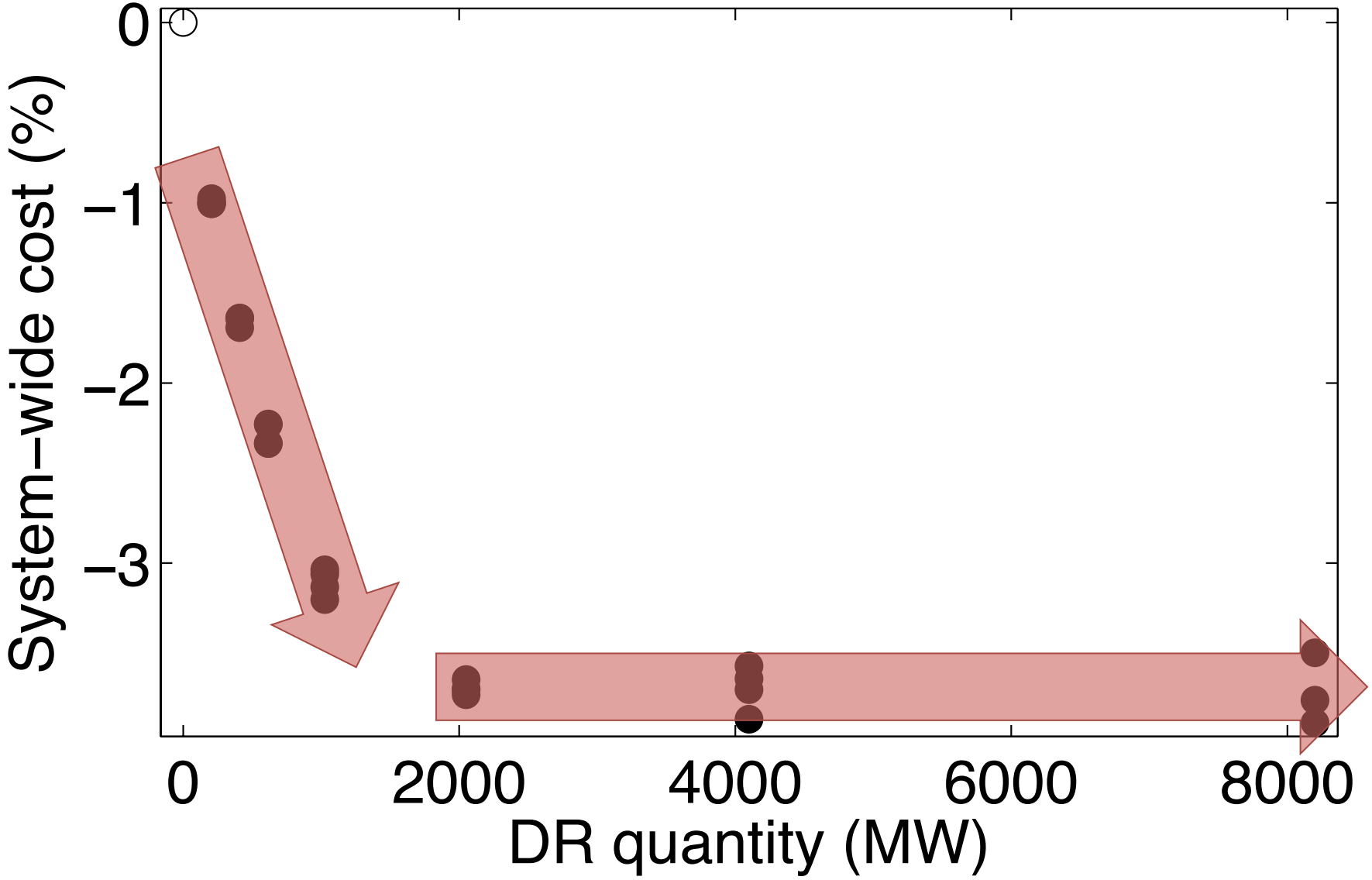
experimental variables

Load shifting resource
24 experiments
(not load clipping)

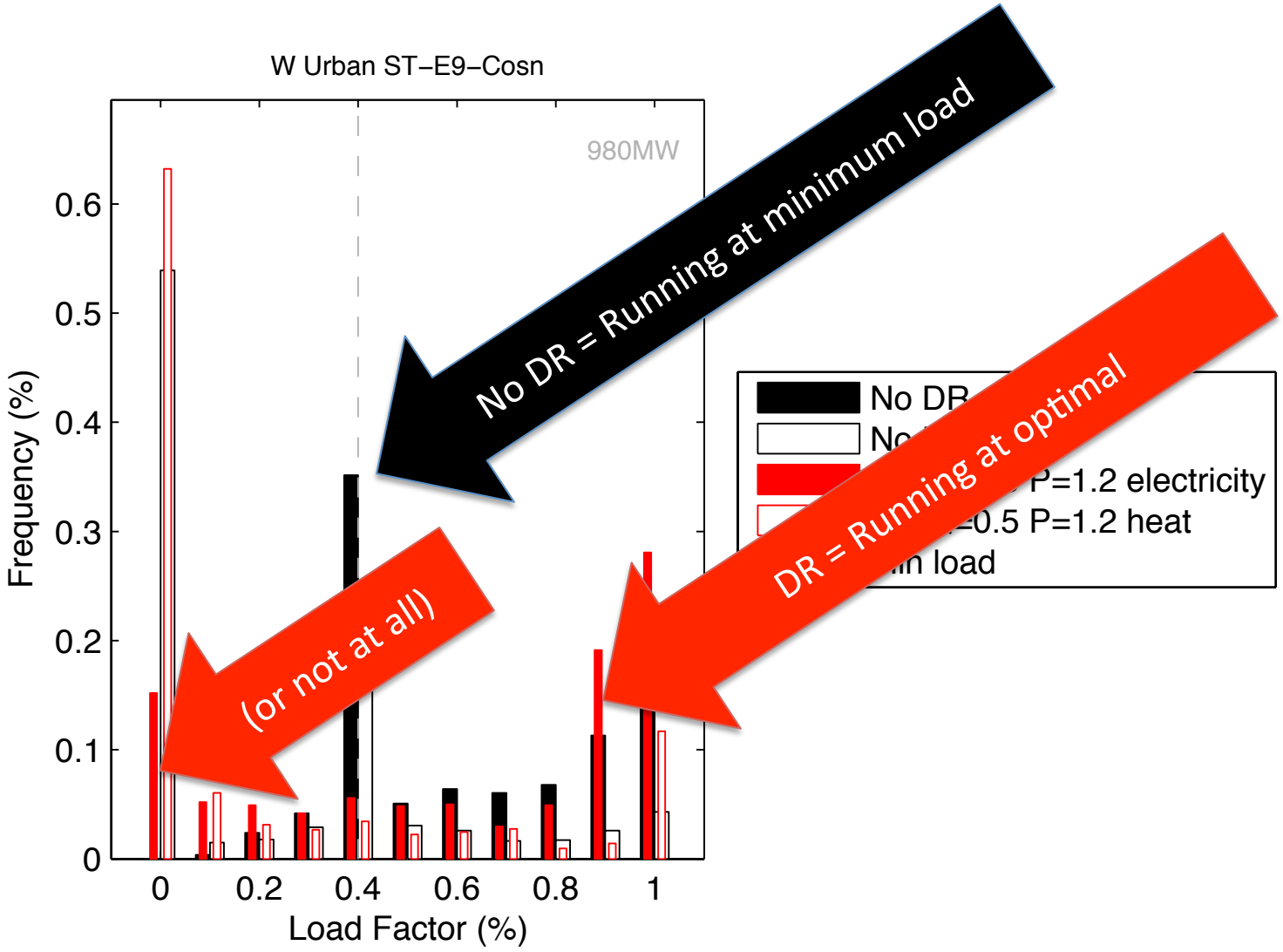
Demand Response in Action



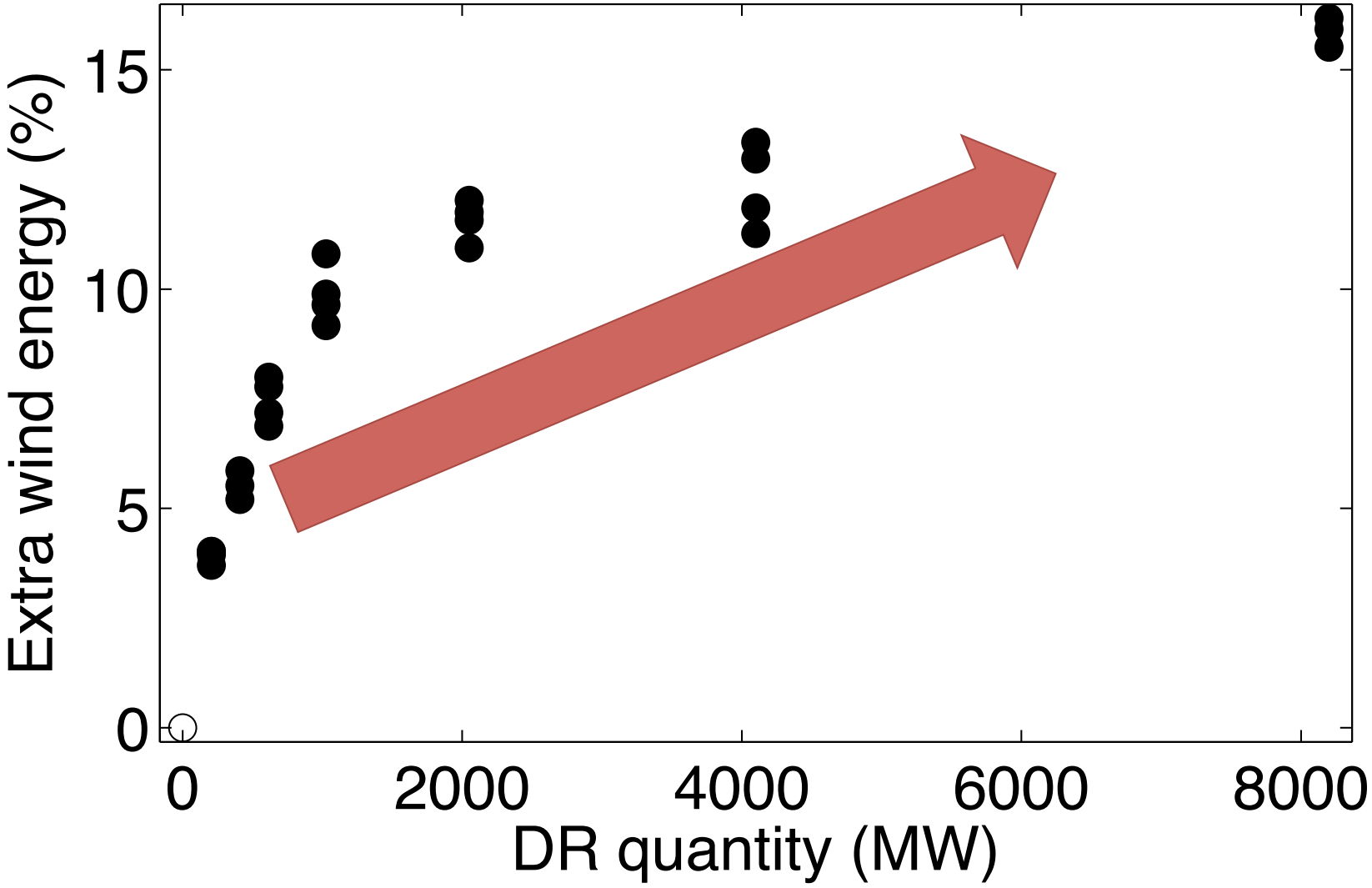
DR Quantity vs System Cost



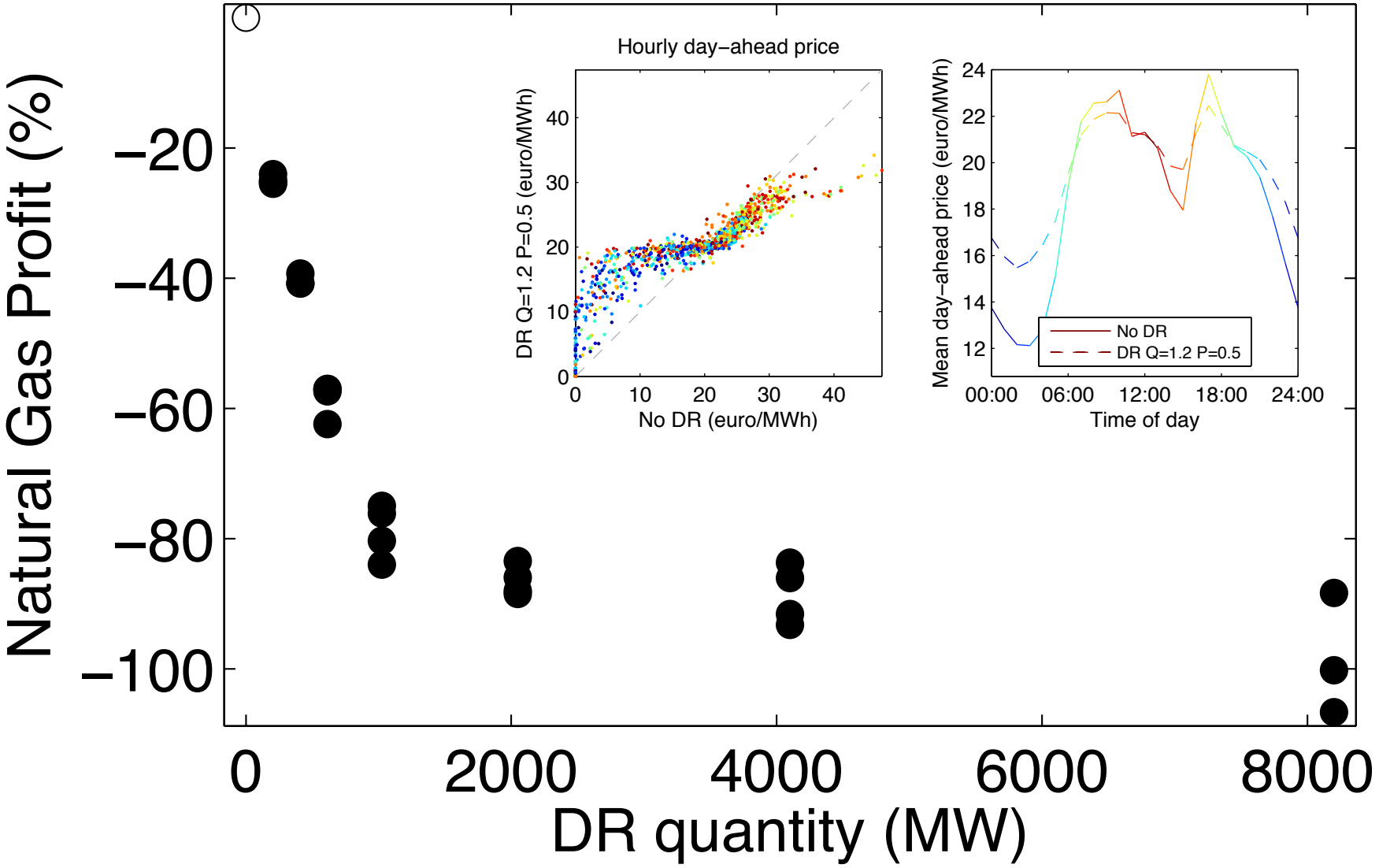
How? Improved Coal Plant Utilization



Increased Wind Generation



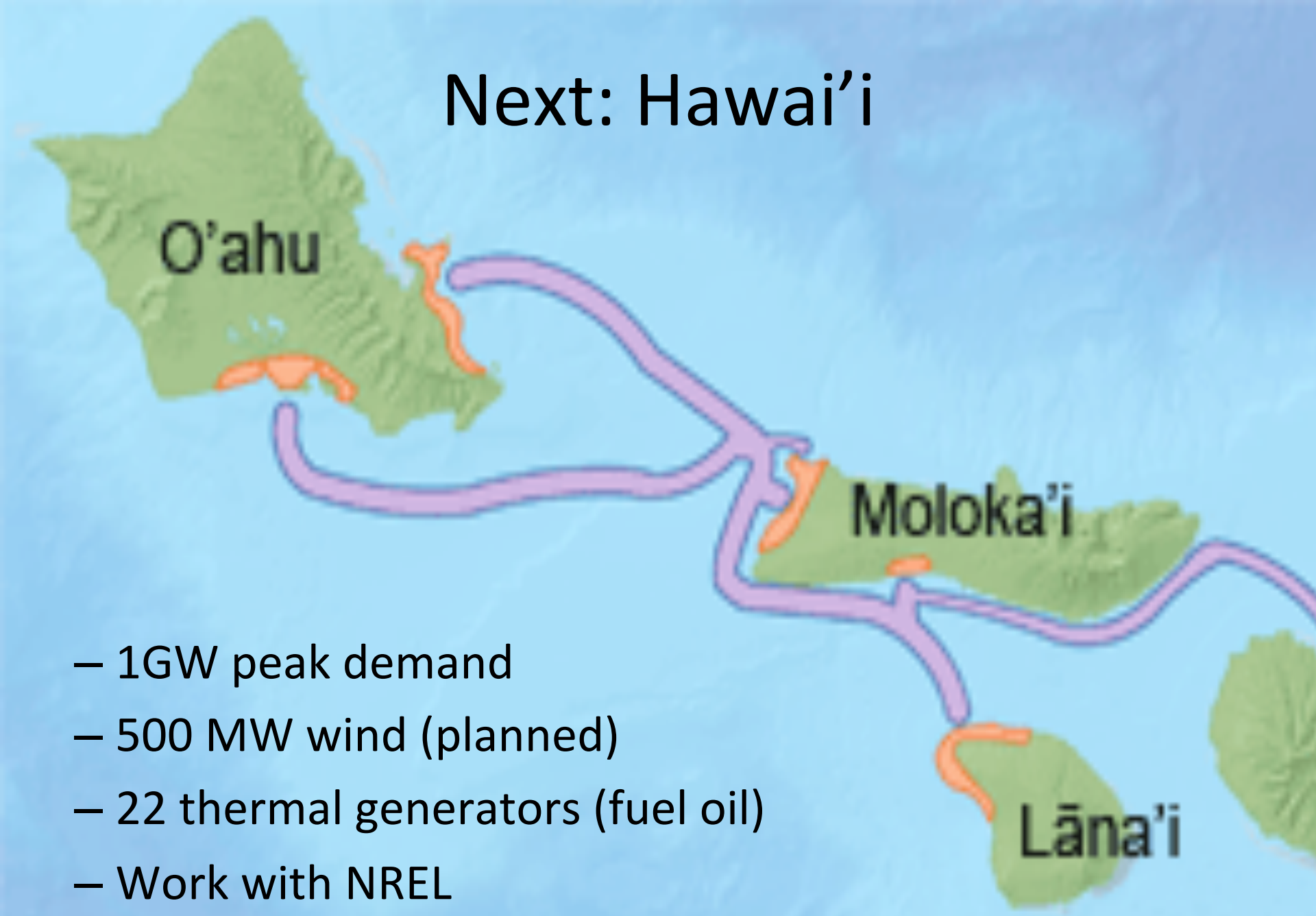
Stakeholder Warning: Natural Gas



DR Stabilizes the Grid

- Reduces operating cost by 3%
  - 10% more wind (less shedding)
  - Coal plants run more efficiently
  - Lower CO_2/SO_2 emissions
- Promising parameters:
  - Quantity: 1025MW (25% of wind power)
  - Price: 60 €/MWh (150% of natural gas)
- Watch out for natural gas plant owners

Next: Hawai'i



- 1GW peak demand
- 500 MW wind (planned)
- 22 thermal generators (fuel oil)
- Work with NREL

Next: Azores

- 132 MW generation capacity
  - 8 heavy fuel oil, 5 geothermal, 7 run-of-river hydro
- 9MW (?) Wind
- 75 MW peak demand

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Economics: Demand Curve