Photovoltaic Generation and the Electric Grid

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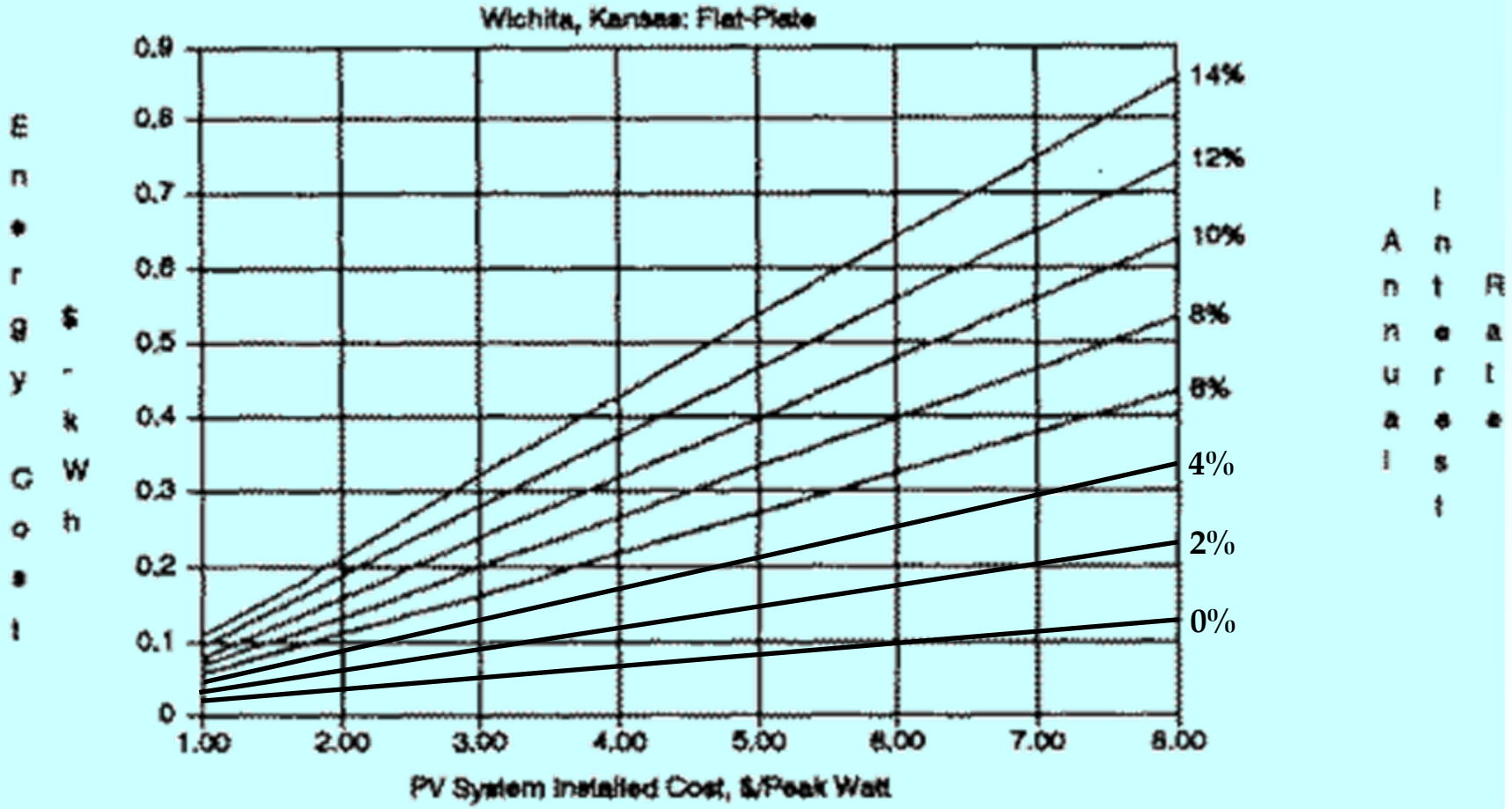
PV electricity cost in Kansas



25% higher cost/lower insolation than Phoenix

Ward Jewell, *An Estimate of the Cost of Energy from Solar Photovoltaic Generation in Kansas*, Report for KRD-201, Kansas Electric Utilities Research Program, 1988.

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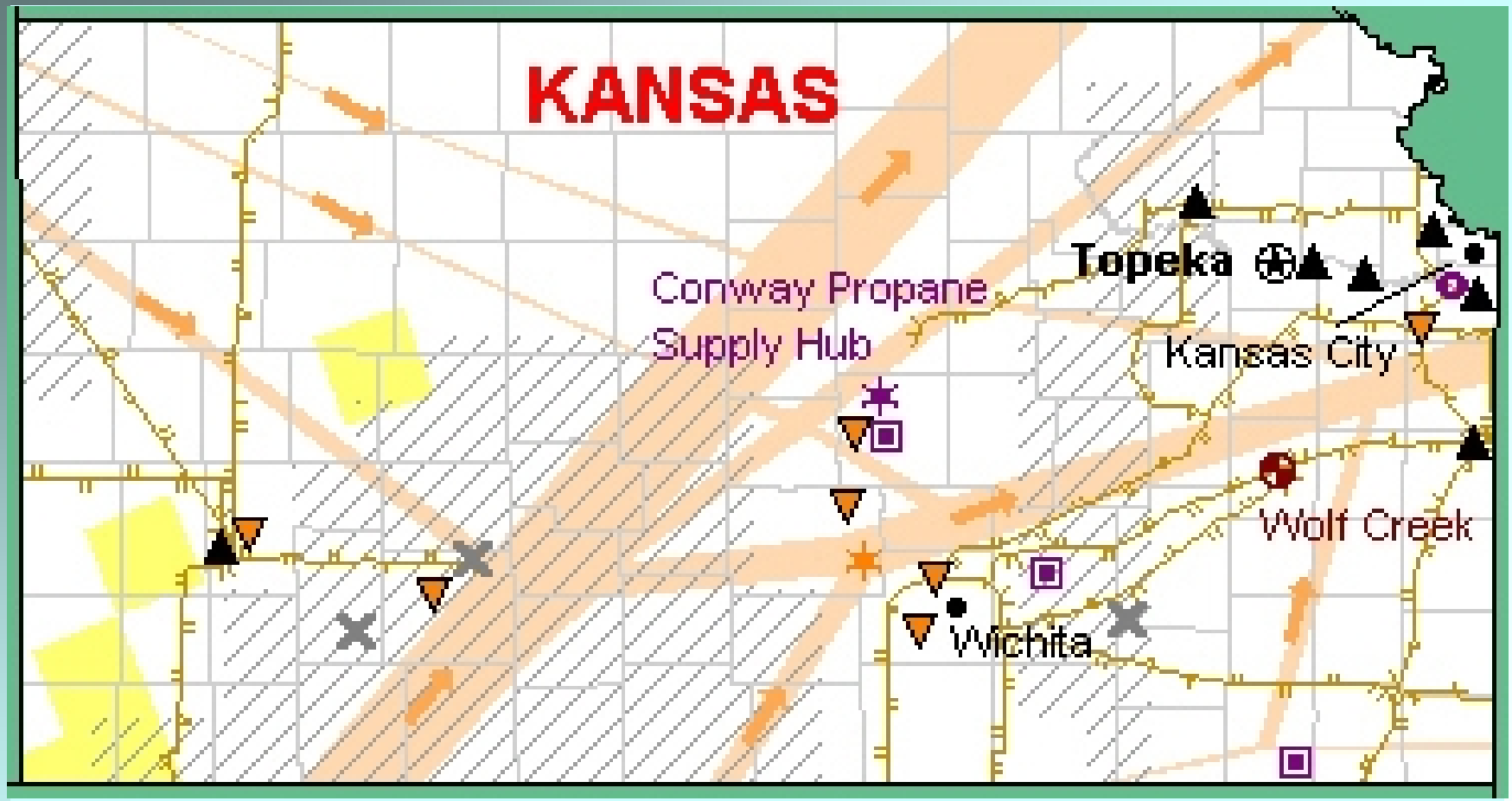

Major Electric Power Plants (>=100 MW)

- Nuclear
- Petroleum
- Coal
- Natural Gas
- Geothermal
- Solar
- Hydroelectric
- Wind
- Wood

Renewable Energy Potential

- Solar - (>= 6.0 kWh/m2/day)
- Wind - (>= 4 Power Class)
- Geo. - (>= 80 milliwatts/m2)

Electric generation in Kansas

Energy Information Administration

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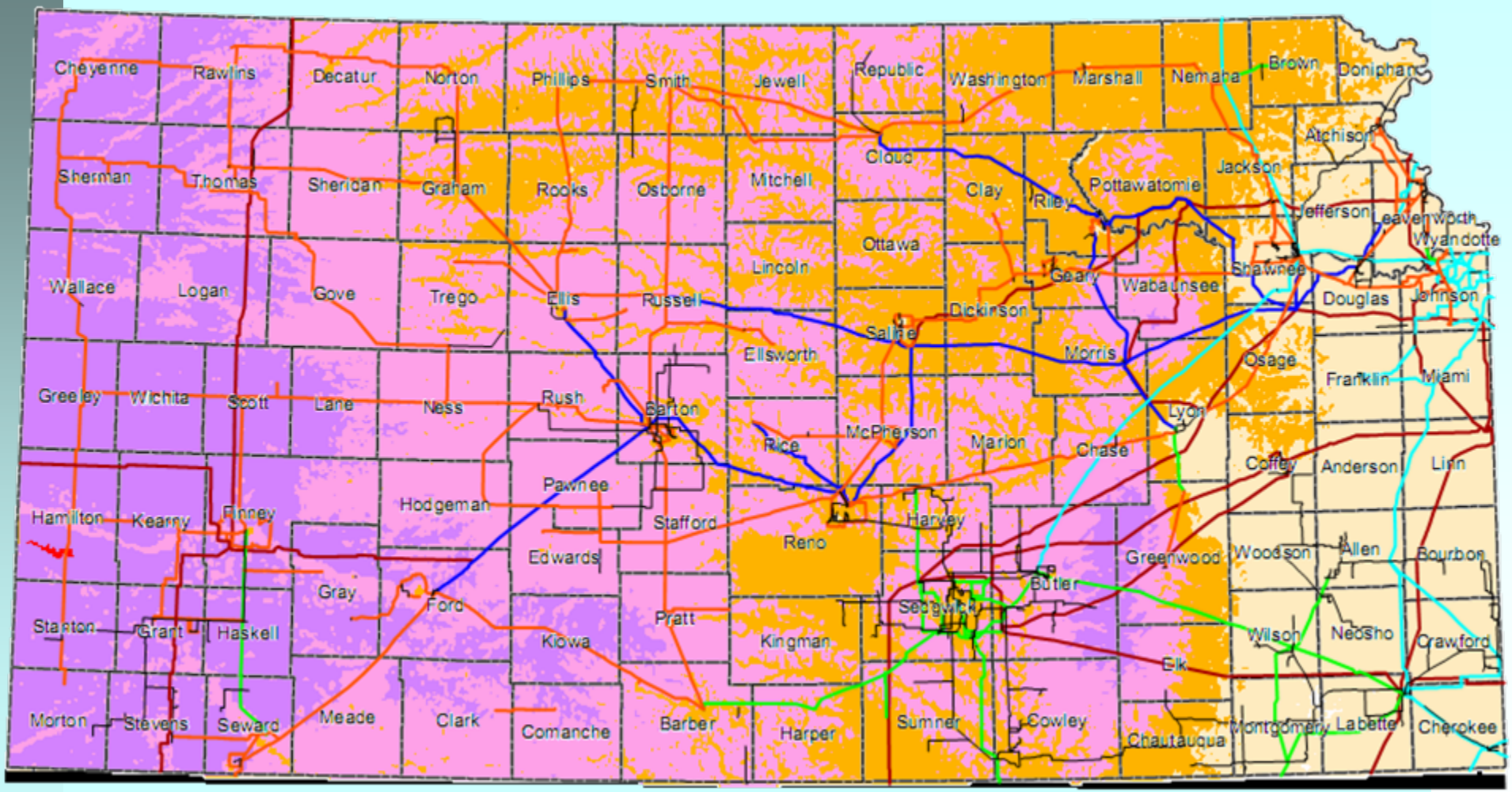
Kansas Electric Transmission Grid



138 - KV
345 - KV
115 - KV
230 - KV
69 - KV
161 - KV

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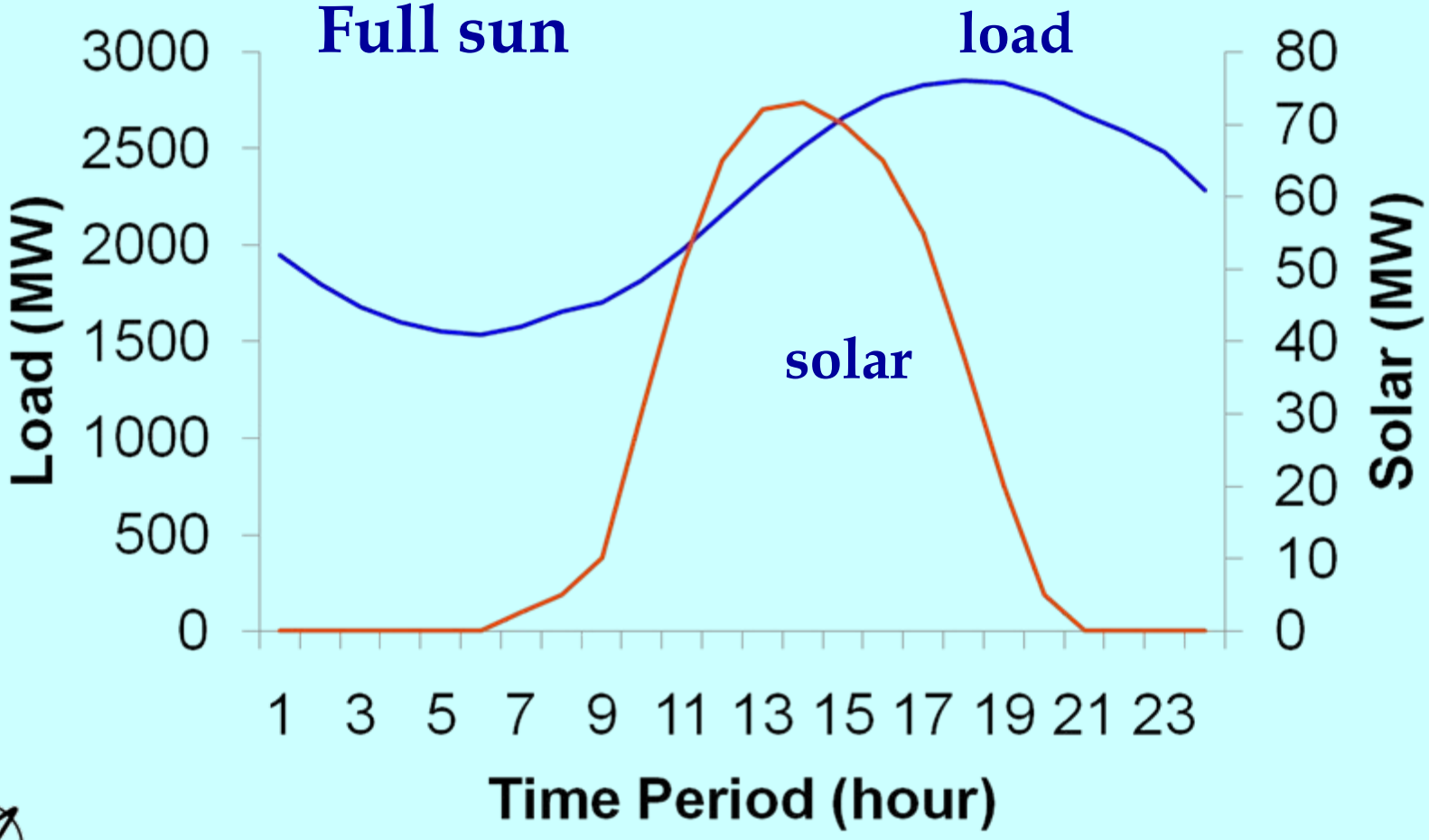
Solar energy and electricity use



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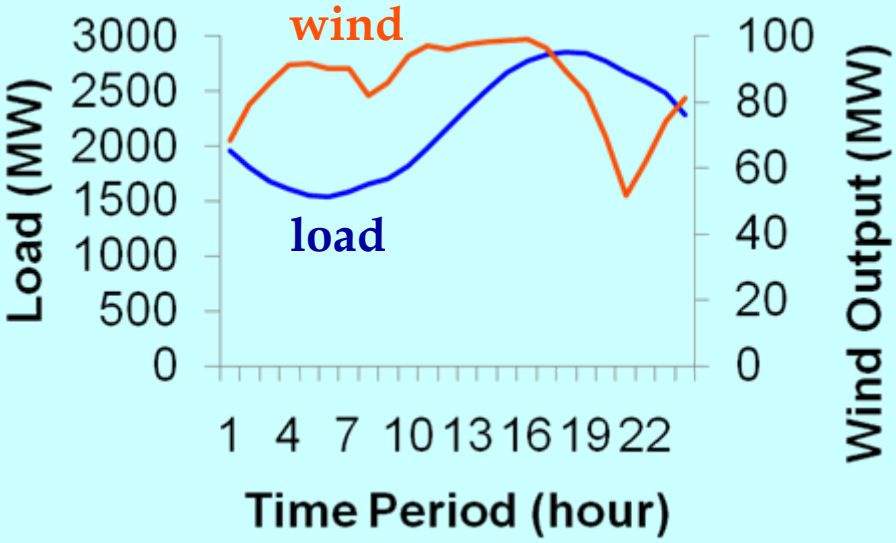
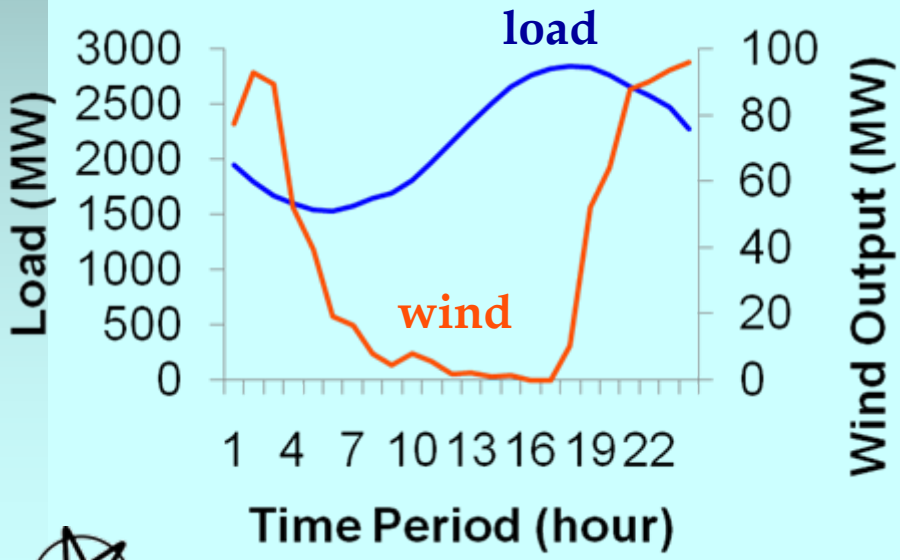
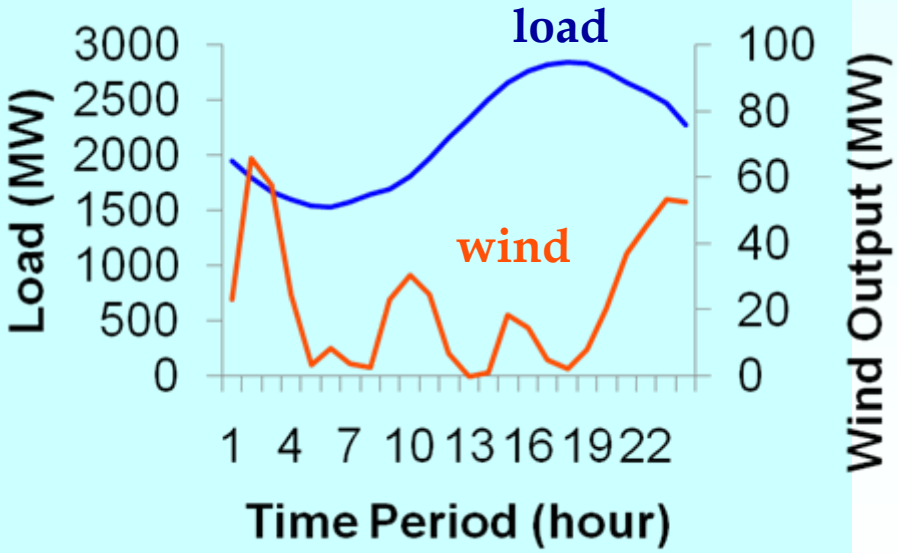
Piyasak Poonpun, *Effects of New Low Carbon Emission Generators and Energy Storage on Greenhouse Gas Emissions in Electric Power Systems,* PhD Dissertation, Wichita State University, 2009.



Wind and electricity use





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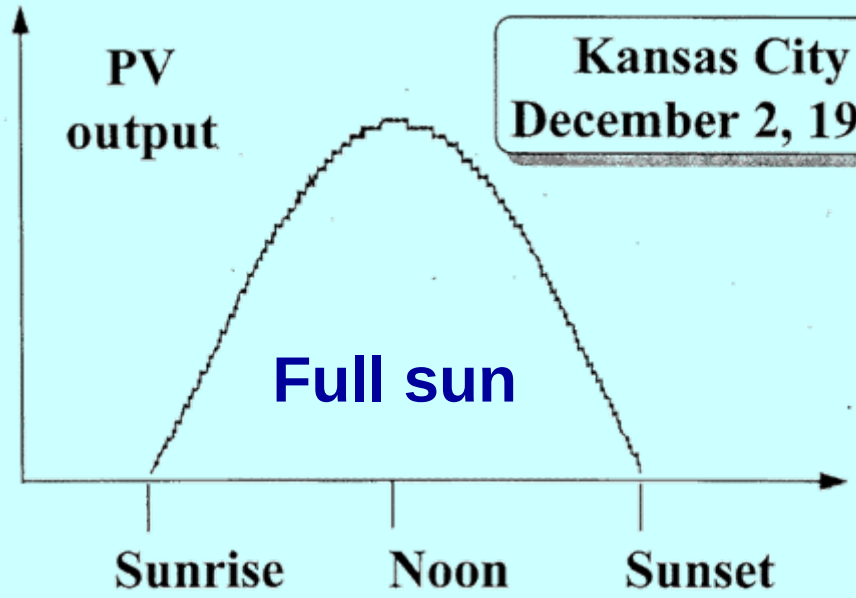
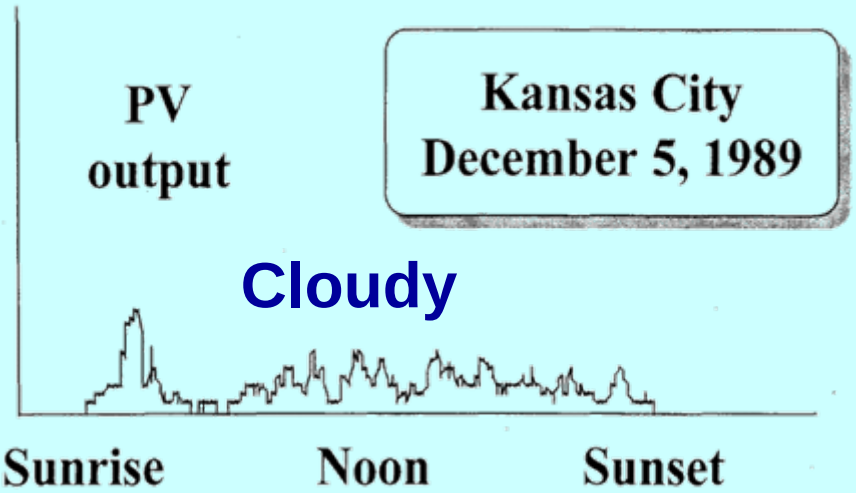
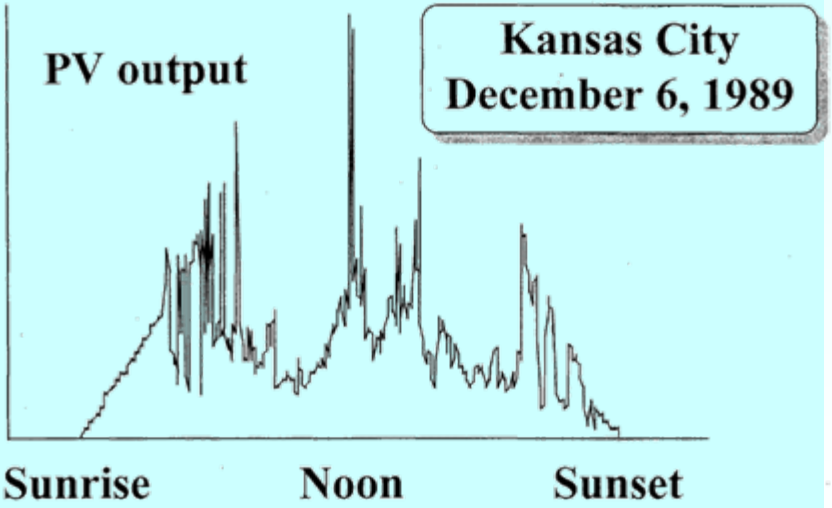
Sunlight varies





Partly cloudy



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R. Ramakumar, Ward Jewell, et al, "Issues in Utility Interactive Photovoltaic Generation," *IEEE Power Engineering Review*, Vol. 14, No. 4, April 1994, pp. 19-21.

Operating Reserves

- Operating reserve requirements:

  5-12% of expected use

  – Must have generation available for 105-112% of expected need

- Capacity credits (California)
  – Coal, nuclear, natural gas, oil, hydro: 100%
  – Solar 89.5%
  – Geothermal 83%
  – Wind 23-25.2%

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Operating Reserves Example

- 1000 MW load, 10% reserve requirement:
  - 1100 MW generation must be available
- Generation includes 100 MW wind farm
  - 25% capacity credit = 25 MW
  - 75 MW additional reserves required
    - total generation needed = 1175 MW
- Generation includes 100 MW solar
  - 89.5% capacity credit = 89.5 MW
  - 10.5 MW additional reserves required
    - total generation needed = 1110.5 MW

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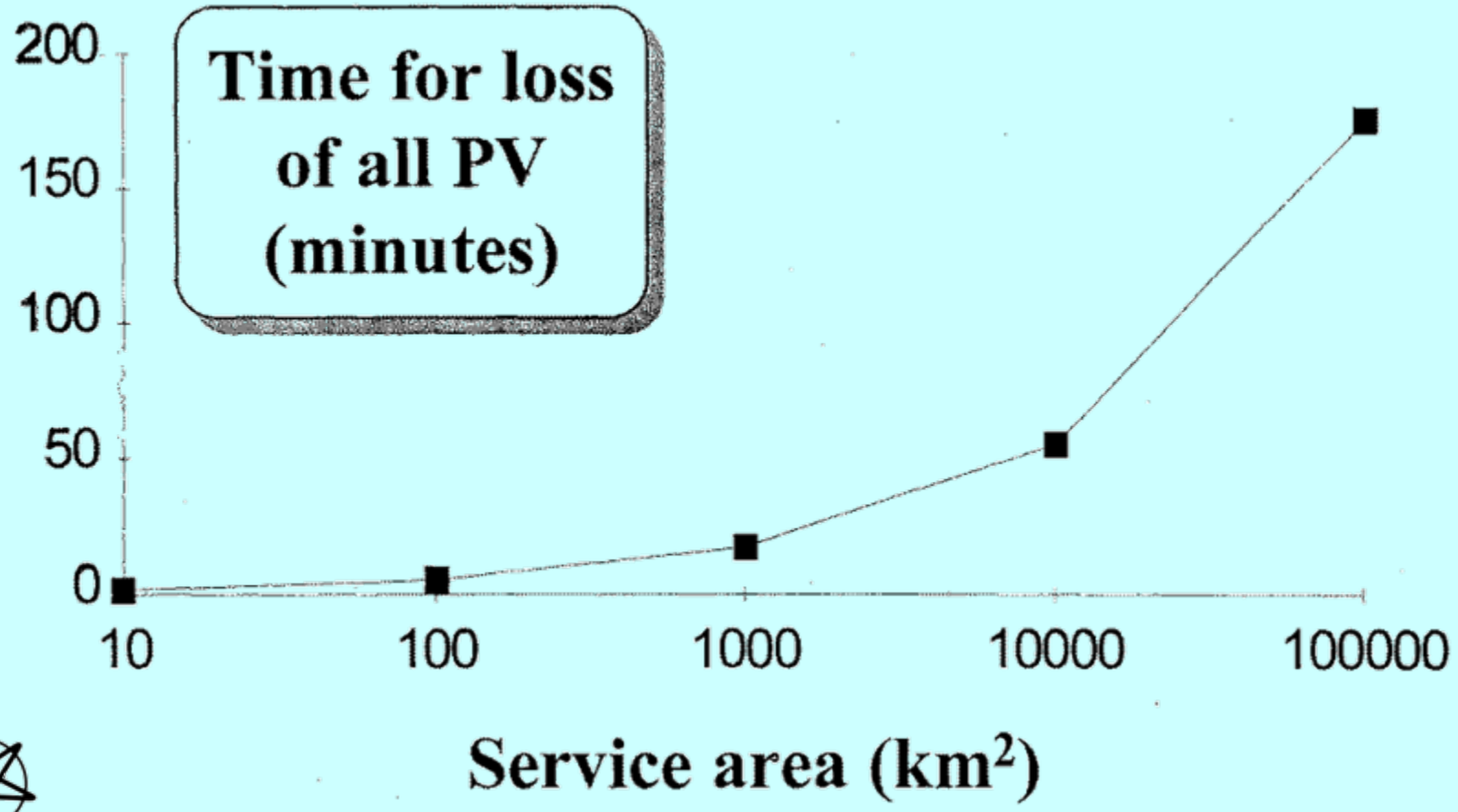
When a squall line moves across an area with PV, all PV generation is lost



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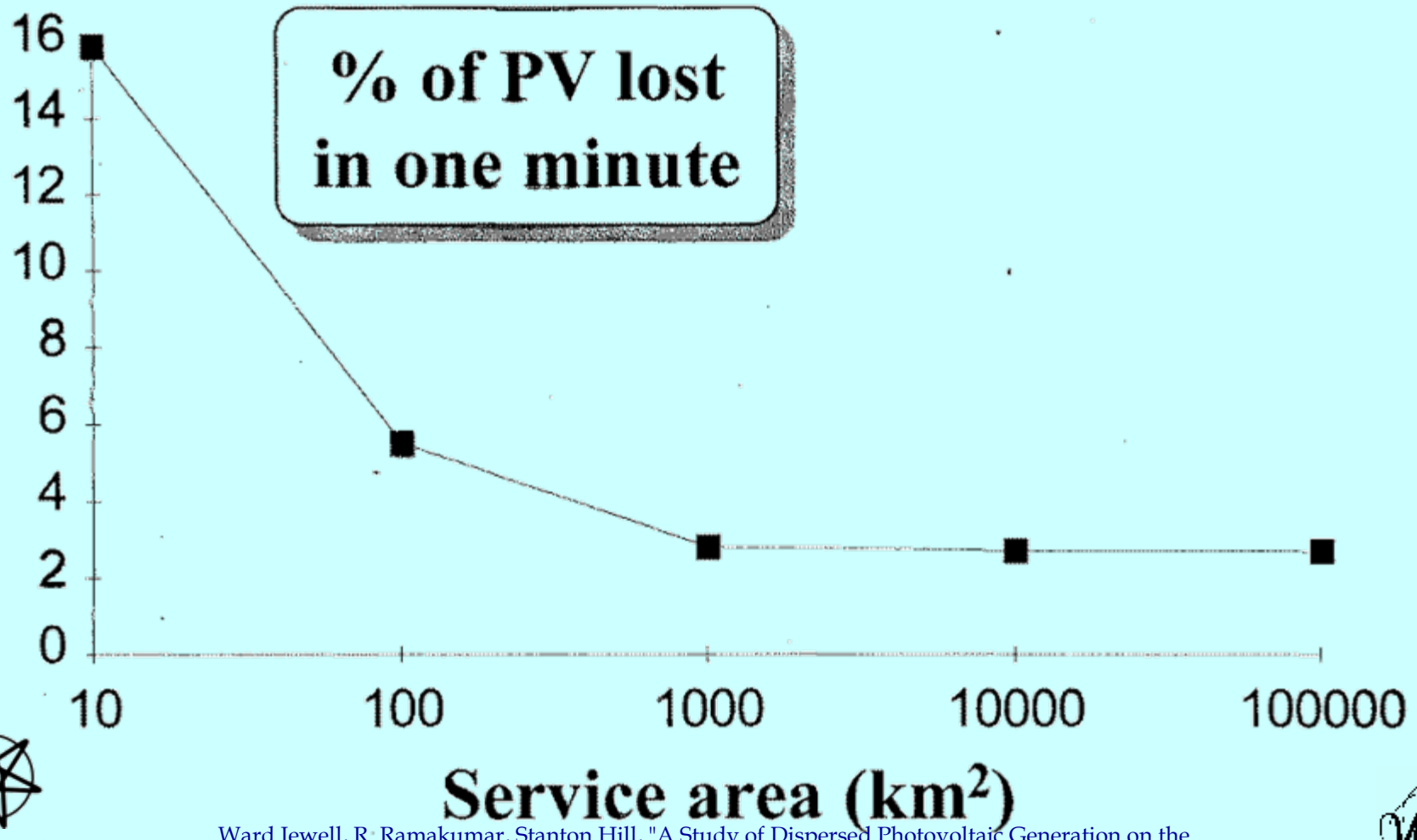
Ward Jewell, R. Ramakumar, Stanton Hill, "A Study of Dispersed Photovoltaic Generation on the PSO System," *IEEE Transactions on Energy Conversion*, Vol. 3, No. 3, September 1988, pp. 473-478.

When clouds are moving over an area with PV, PV generation varies rapidly



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Public Service of Oklahoma (AEP) southeast Tulsa area
(450 square kilometers)

15% dispersed PV can cause:

- ***Transmission power flow reversal***
- ***Transmission overloads***

under certain conditions.

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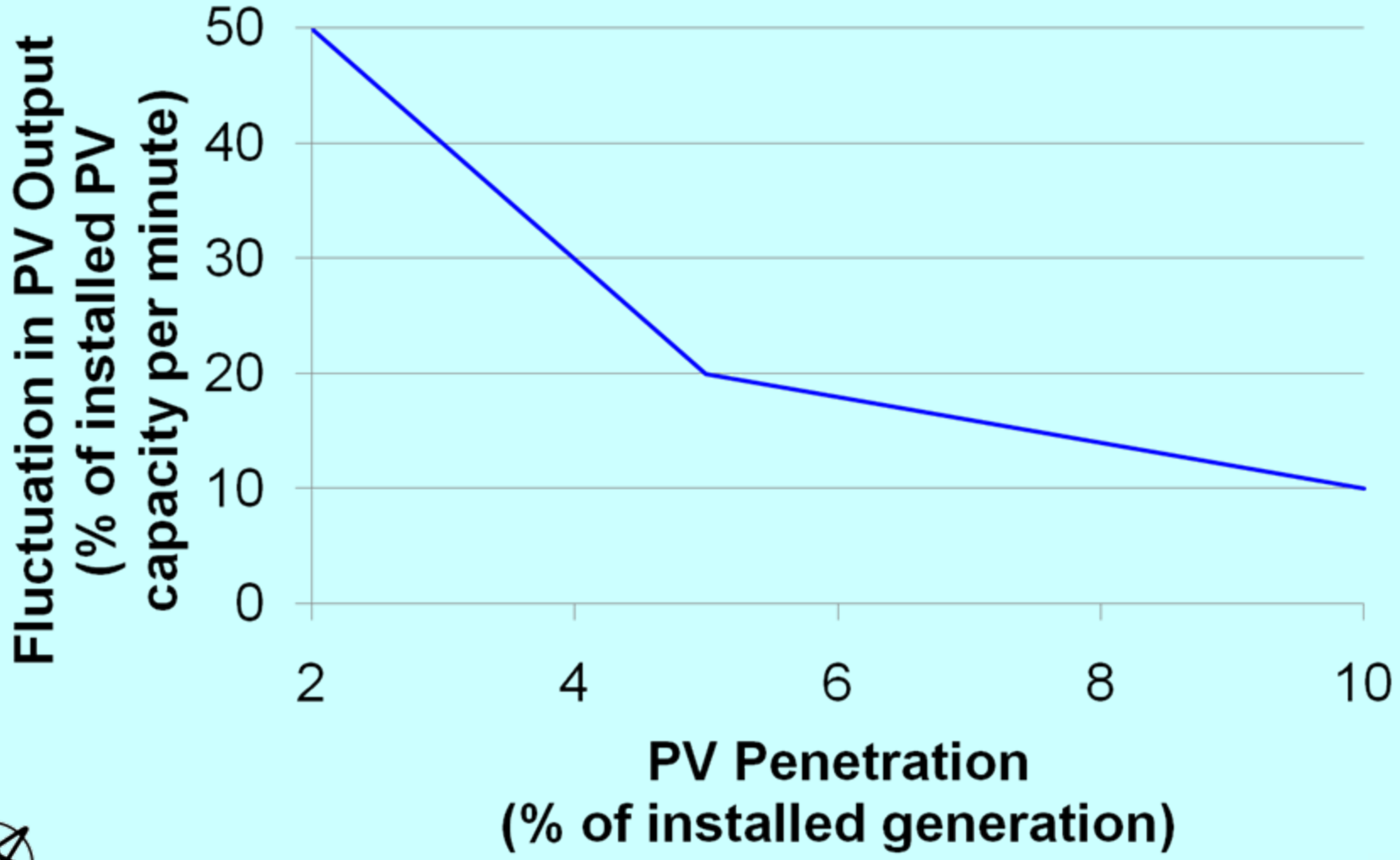
Ward Jewell, R. Ramakumar, Stanton Hill, "A Study of Dispersed Photovoltaic Generation on the PSO System," *IEEE Transactions on Energy Conversion*, Vol. 3, No. 3, September 1988, pp. 473-478.

Kansas utility
ramp rate limited



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Ward Jewell, Timothy D. Unruh, "Limits on Cloud Induced Fluctuation from Photovoltaic Generation," *IEEE Transactions on Energy Conversion*, Vol. 5, No. 1, March 1990, pp. 8 14.

Kansas Utility

System ramp rate 1% of load/minute

One PV generator with capacity = 1.3% of load may exceed system ramp rate under certain conditions.

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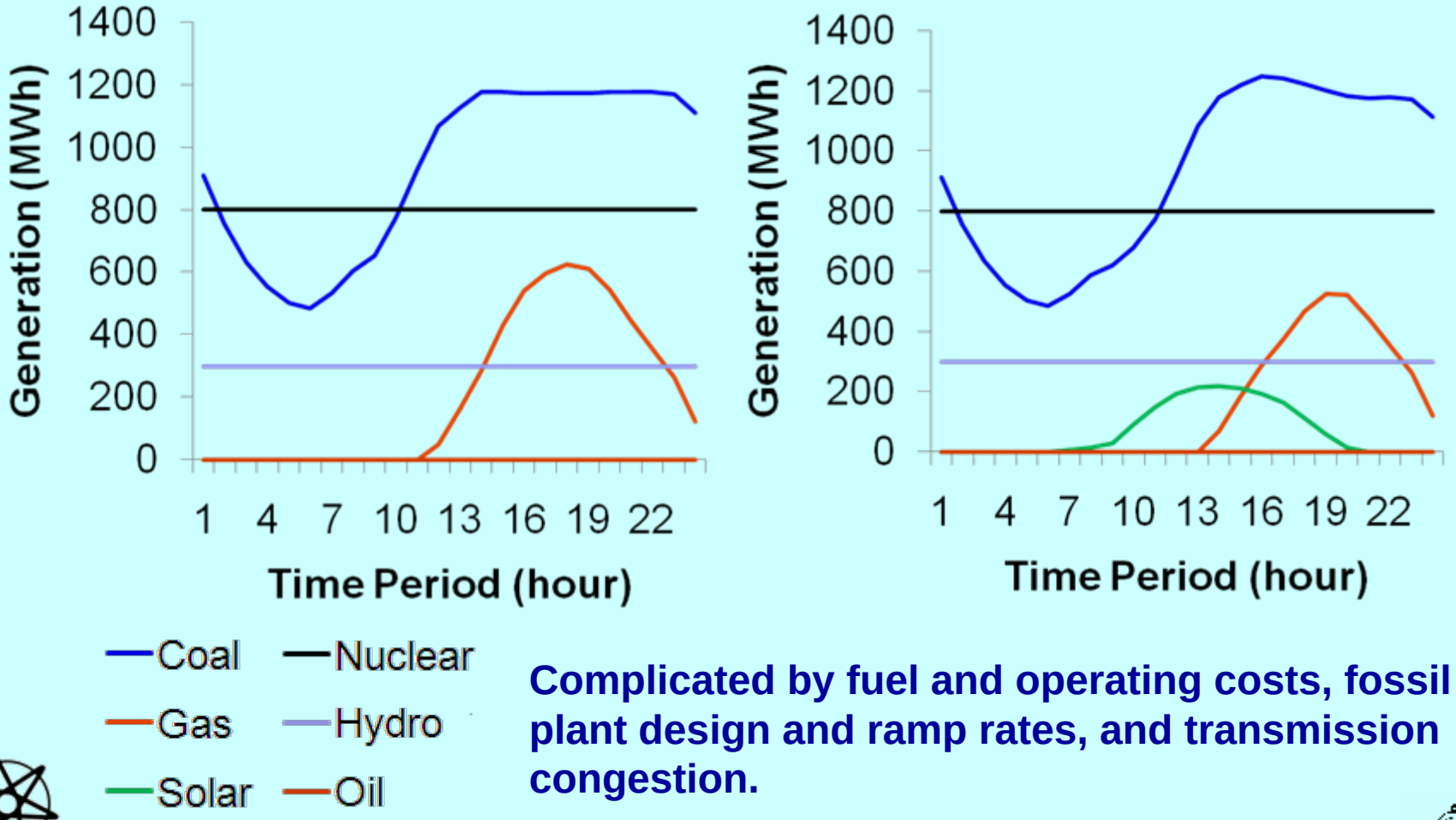
Ward Jewell, Timothy D. Unruh, "Limits on Cloud Induced Fluctuation from Photovoltaic Generation," *IEEE Transactions on Energy Conversion*, Vol. 5, No. 1, March 1990, pp. 8 14.

Displacement of fossil generation by 300 MW PV, no CO_2 price



Complicated by fuel and operating costs, fossil plant design and ramp rates, and transmission congestion.

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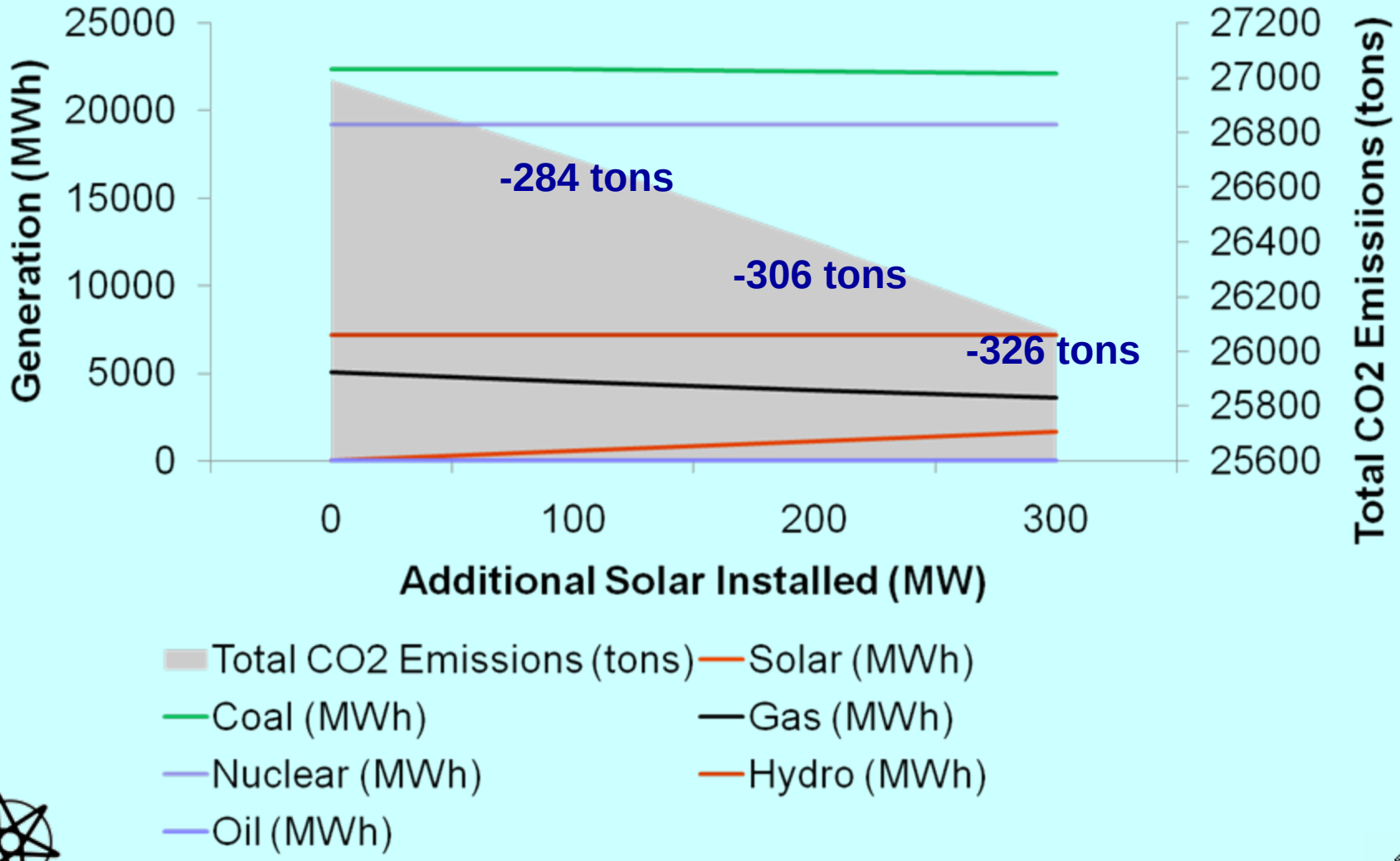
Reductions in CO_2



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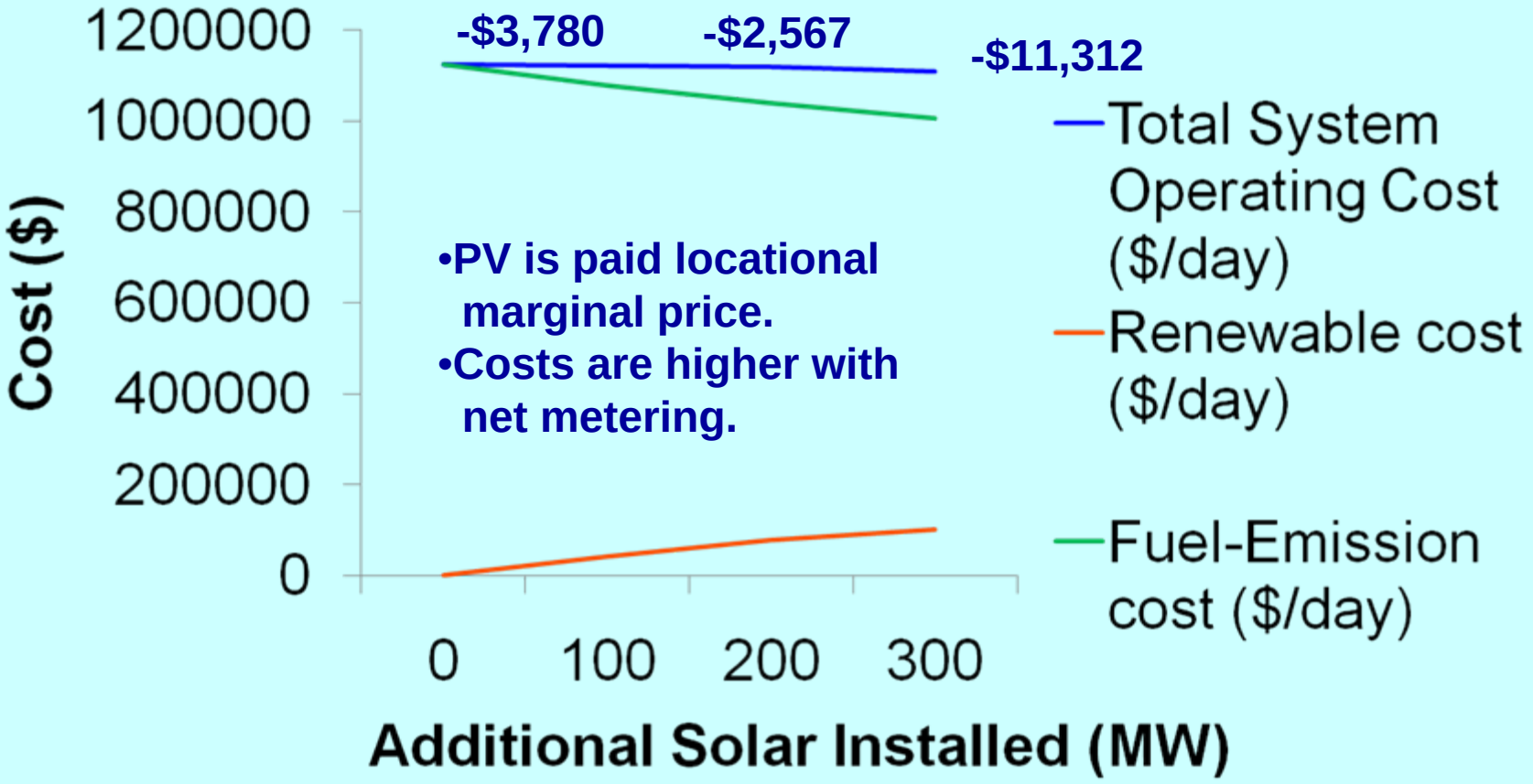
Changes in costs



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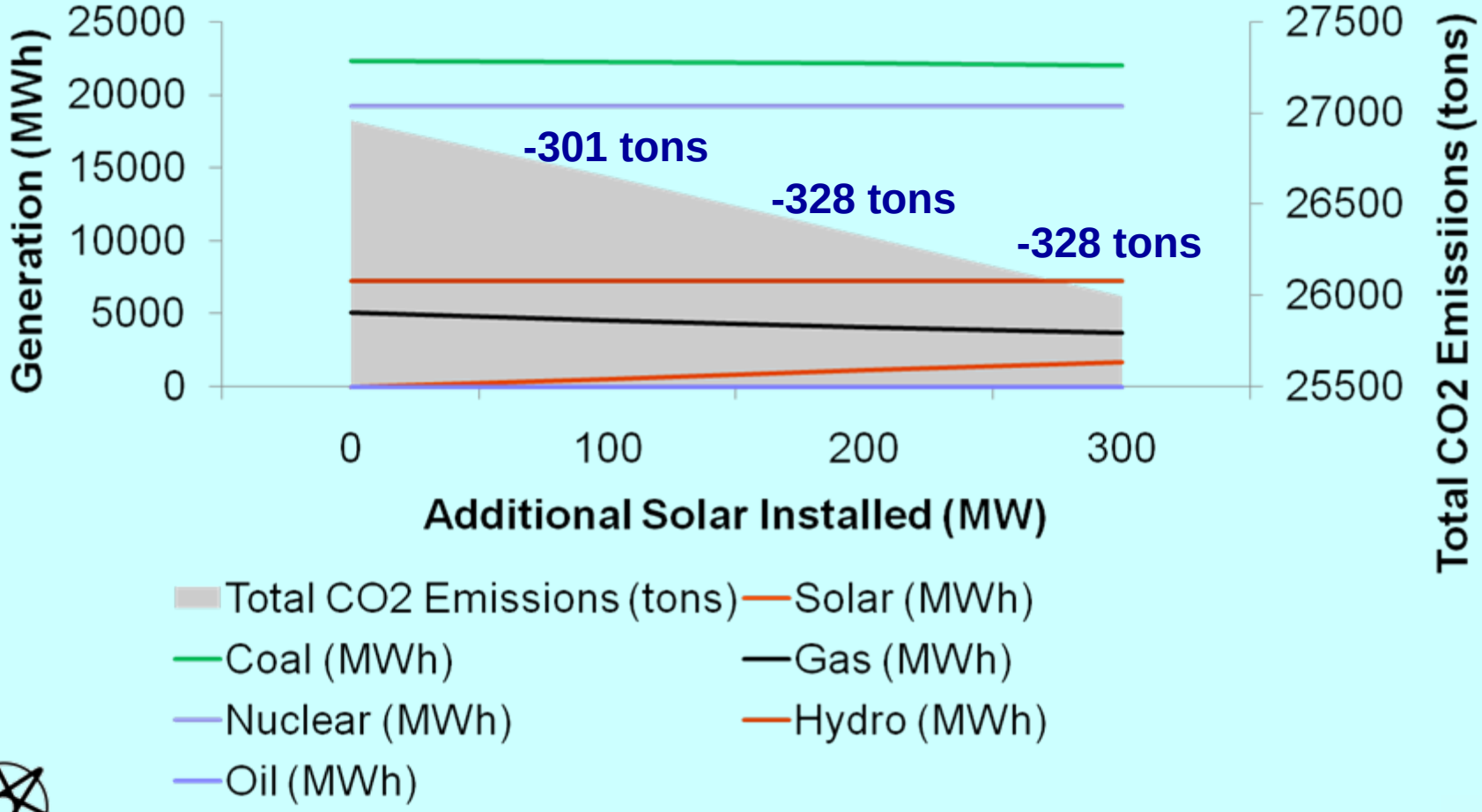
CO_2 reductions are greater with $50/ton CO_2 tax

Total costs increase



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- PV reduces CO2 emissions and conserves natural gas
- Variability of PV and complexity of grid make cost and CO2 calculations complicated
- PV matches electric use better than wind
- System must have installed generation to make up for unavailability of PV
- Payments to PV and operating costs are unrelated to cost of building and operating PV
- Higher payments to PV means higher electric rates

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Thanks to
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