The Cannibalization Effect of Wind and Solar in the California Wholesale Electricity Market

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Outline

- The rise of variable renewables
- The merit order and the cannibalization effect
- Absolute and relative cannibalization effect
- Conclusions
- Further research: demand and supply side cannibalization effect

The rise of variable renewables in California

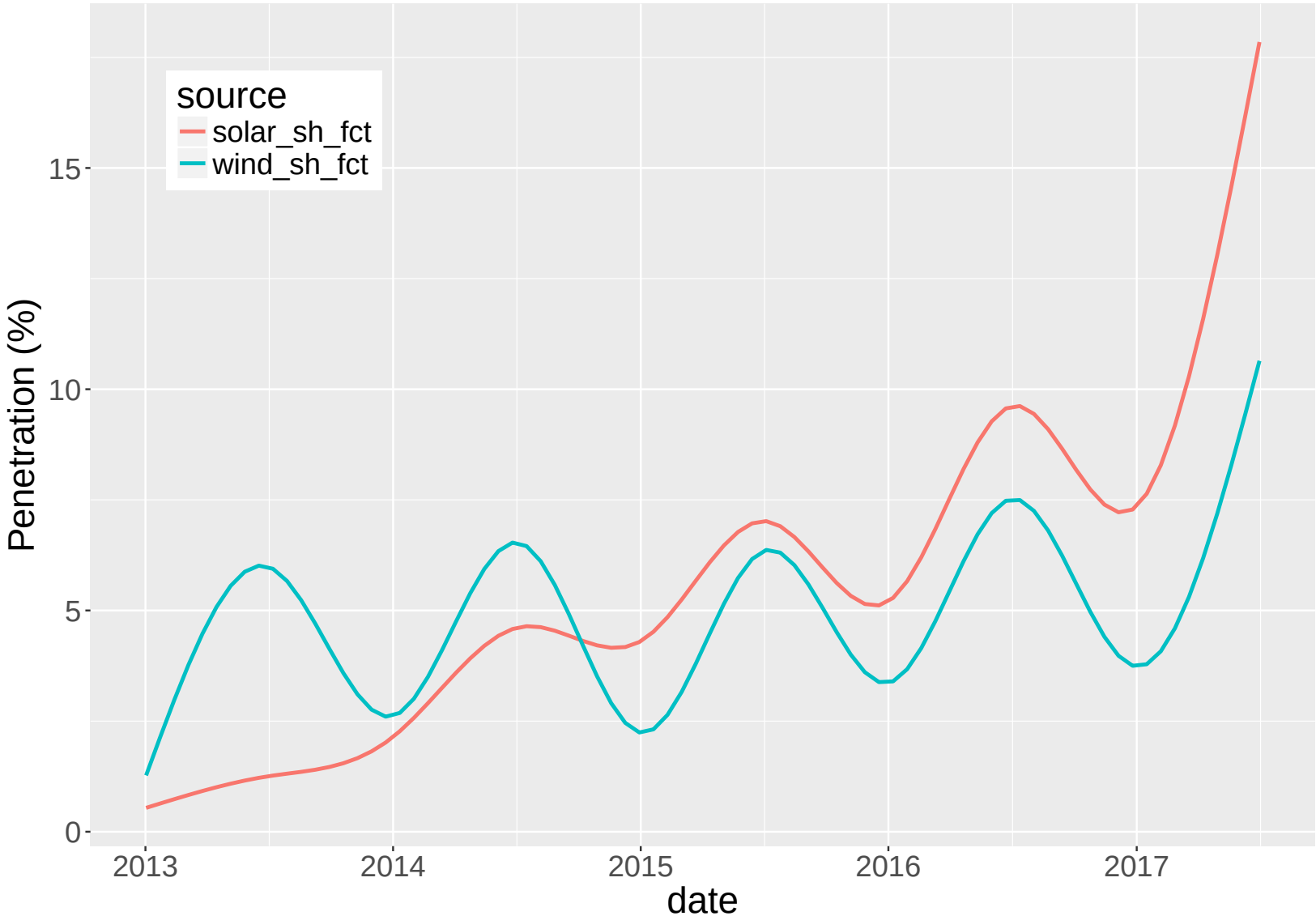

Figure 1: Smoothed daily solar and wind penetration

The merit-order effect

- Renewable energies pressure down electricity prices

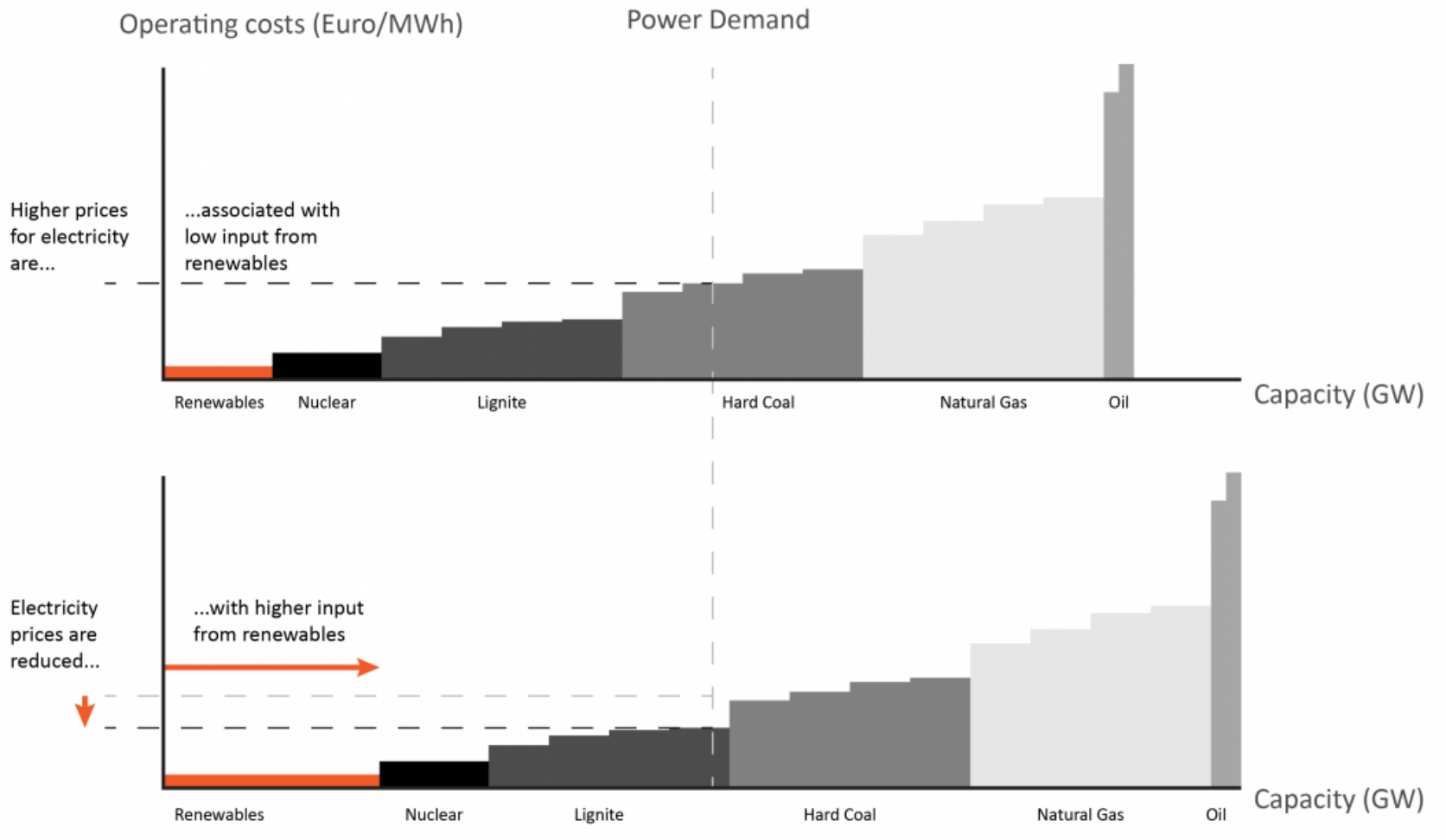

Figure 2: The merit order effect. Source: CLEW 2016

The cannibalization effect

The higher solar/wind electricity penetration, the lower its value

- Absolute cannibalization: (solar) daily unit revenues (p_d^s):

$$p_d^s = \frac{\sum_{t=1}^{24} p_t q_t^s}{\sum_{t=1}^{24} q_t^s}$$

- Relative cannibalization: value factor (VF):
  unit revenue (p_d^s) divided by daily avg. wholesale price ($\overline{p_d}$)

$$VF_d^s = \frac{p_d^s}{\overline{p_d}} = \frac{\frac{\sum_{t=1}^{24} p_t q_t^s}{\sum_{t=1}^{24} q_t^s}}{\frac{\sum_{t=1}^{24} p_t}{24}}$$

$p = price;\ q = quantity;$

$^s : solar;\ _t : time(hour);\ _d : day$

Unit revenue and value factor visualized

$$VF_d > 1 \Leftrightarrow p_d^s > \overline{p_d}$$

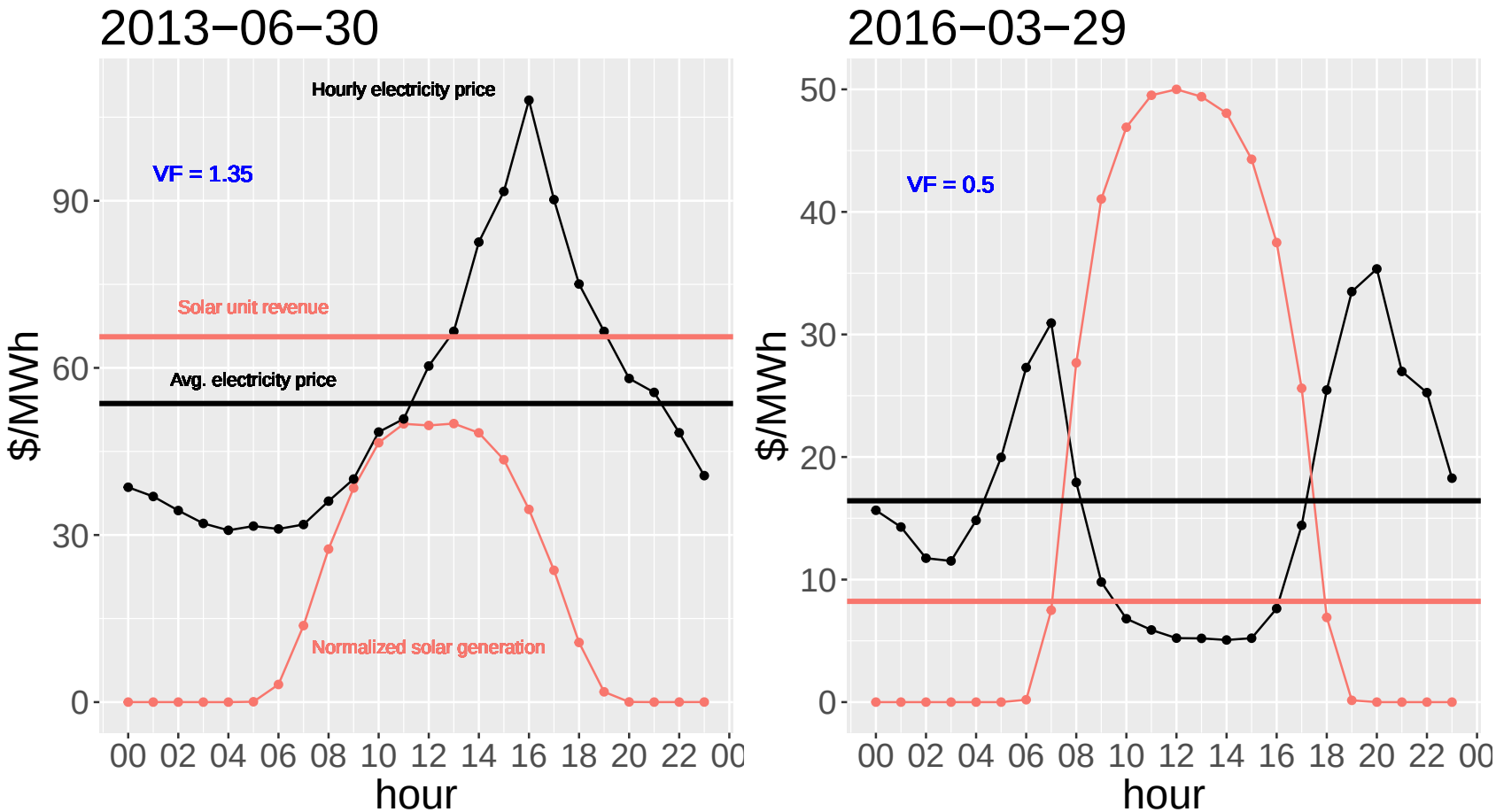

Figure 3: Calculation of daily value factors from hourly data

Modeling the cannibalization effect

- Absolute:

$$p_d^s = \alpha + \beta_1 q_d^s + \beta_2 q_d^w + \beta_3 p_d^g + \beta_4 d_d + \gamma' D_d + \epsilon_d$$

- Relative:

$$VF_d^s = \alpha + \beta_1 (q_d^s / d_d) + \beta_2 (q_d^w / d_d) + \beta_3 p_d^g + \gamma' D_d + \epsilon_d$$

$q = quantity$; $d = demand$; $p = price$; $D = vector\ of\ time\ dummies$

$^s : solar$; $^w : wind$; $^g : gas$

Absolute cannibalization: Unit Revenues

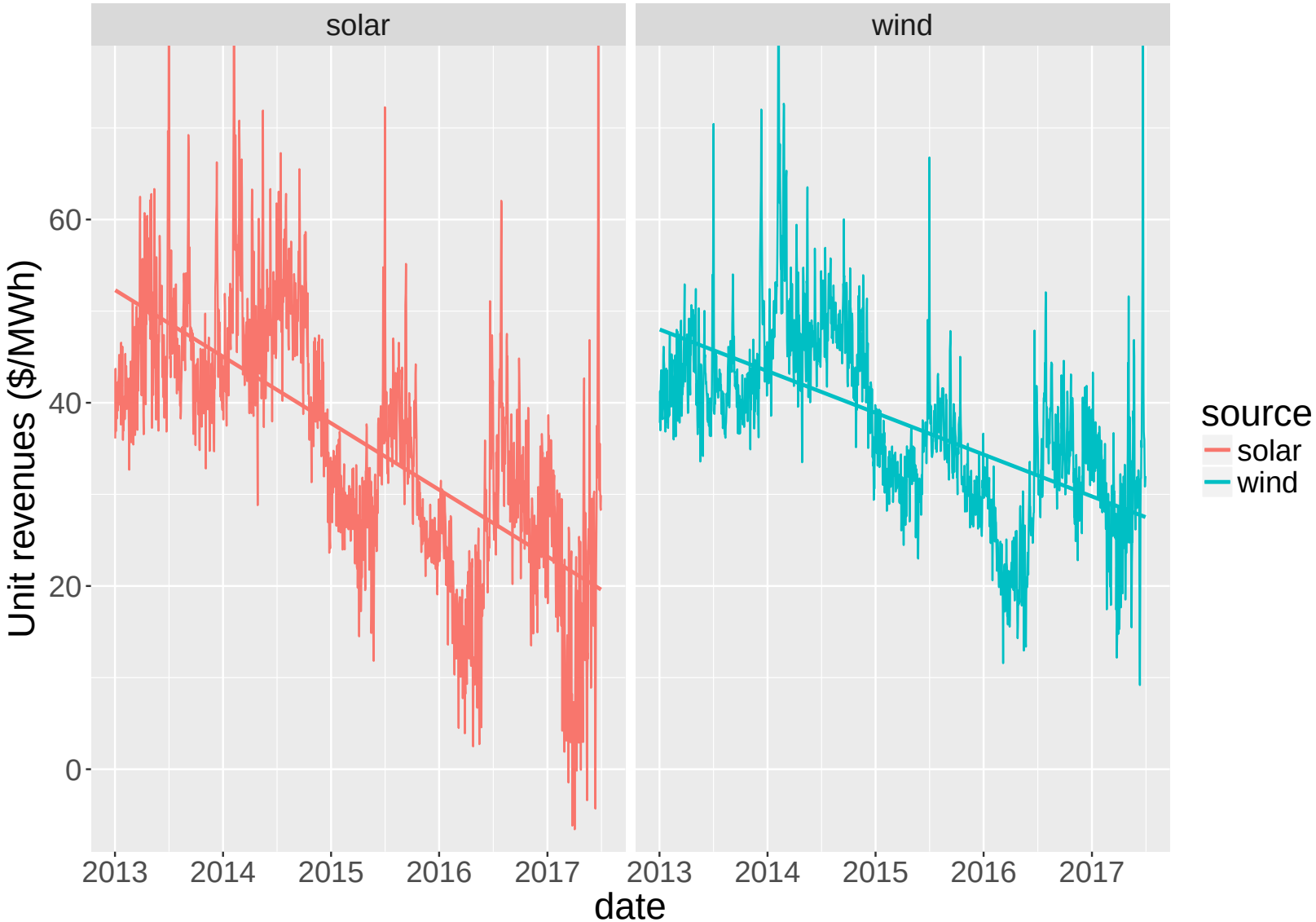

Figure 4: Daily solar and wind unit revenues

Electricity prices

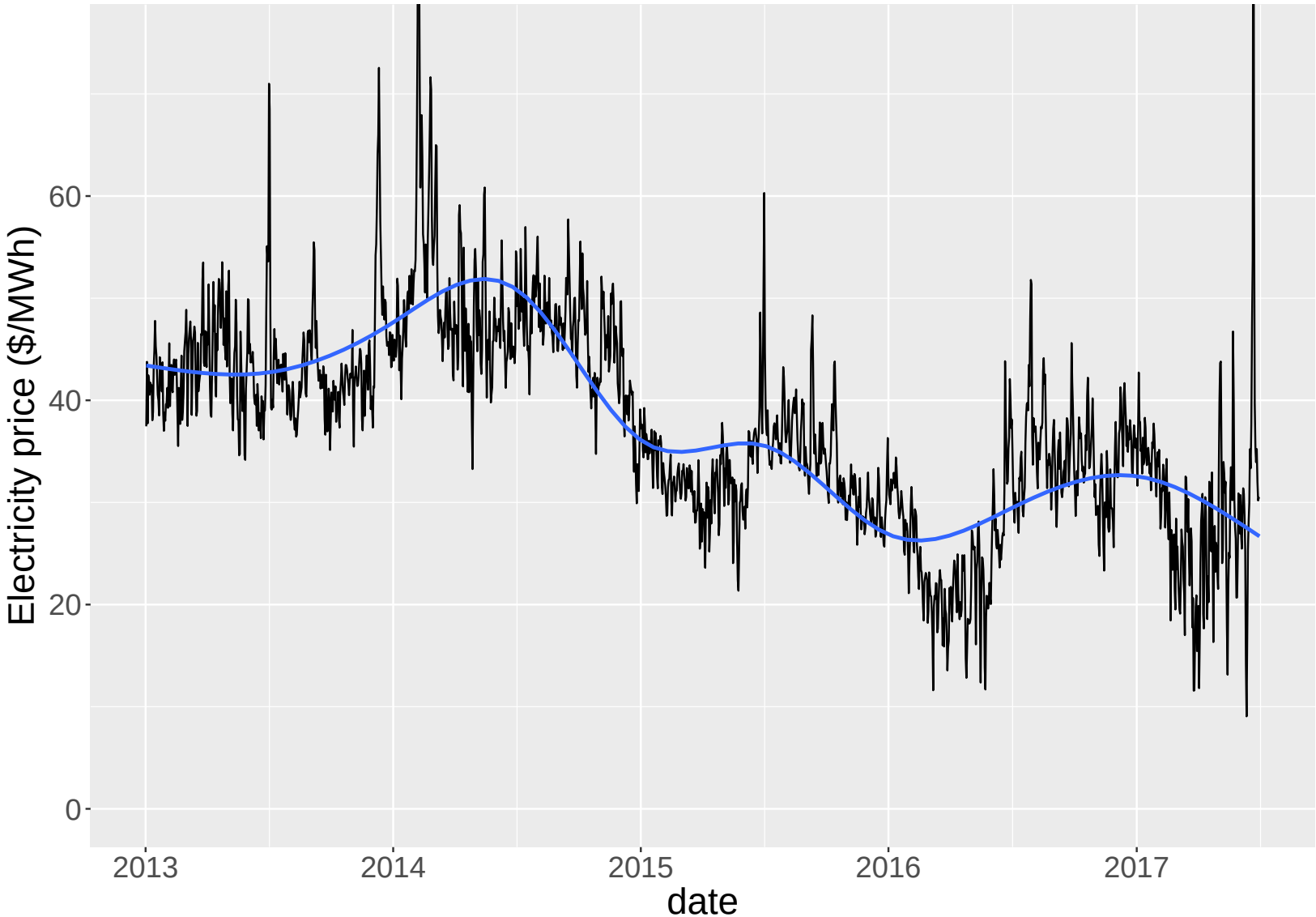

Figure 5: Daily electricity prices

Relative cannibalization: Value Factors

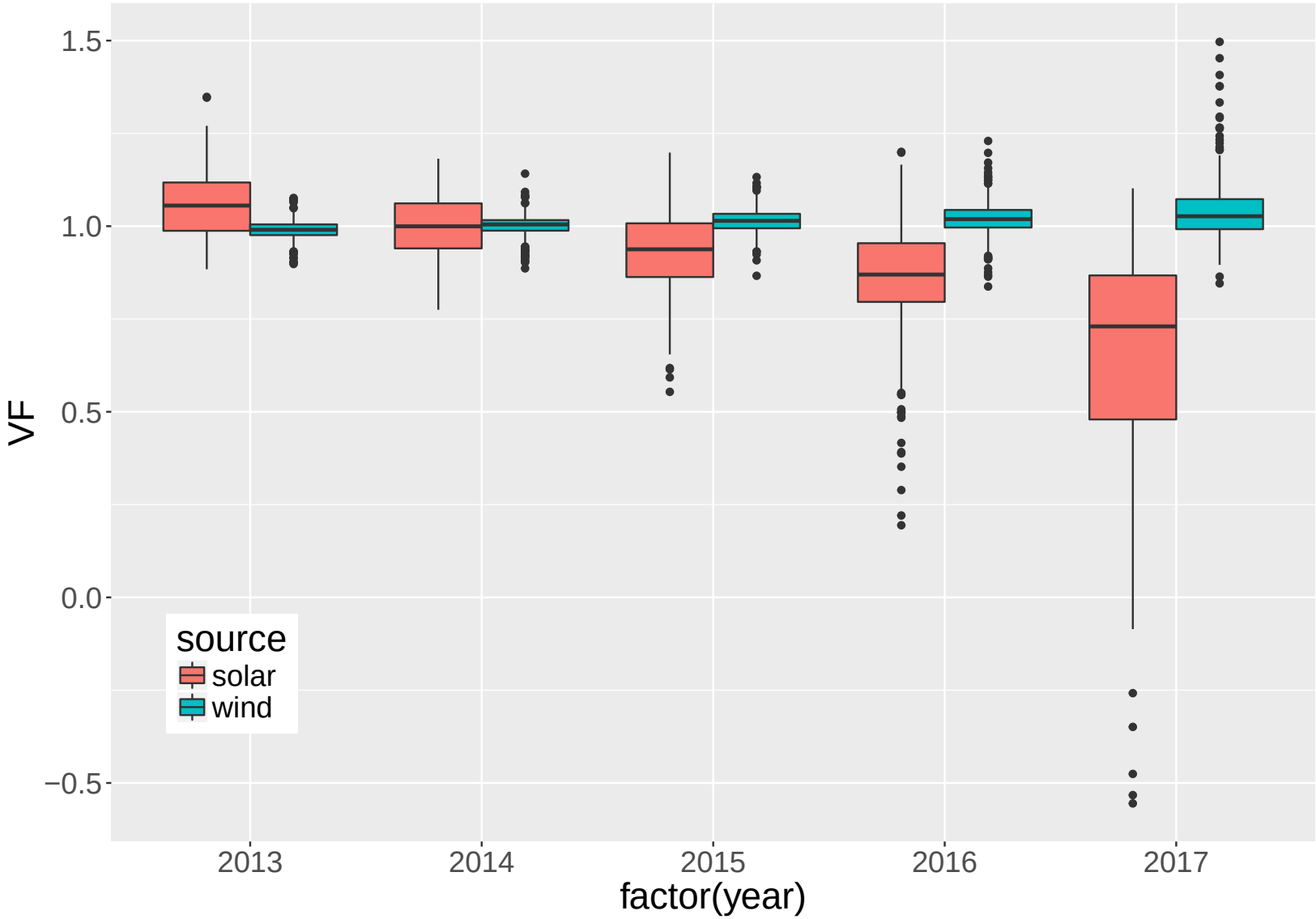

Figure 6: Wind and solar Value Factors descriptive statistics over time

Relative cannibalization: Value Factors

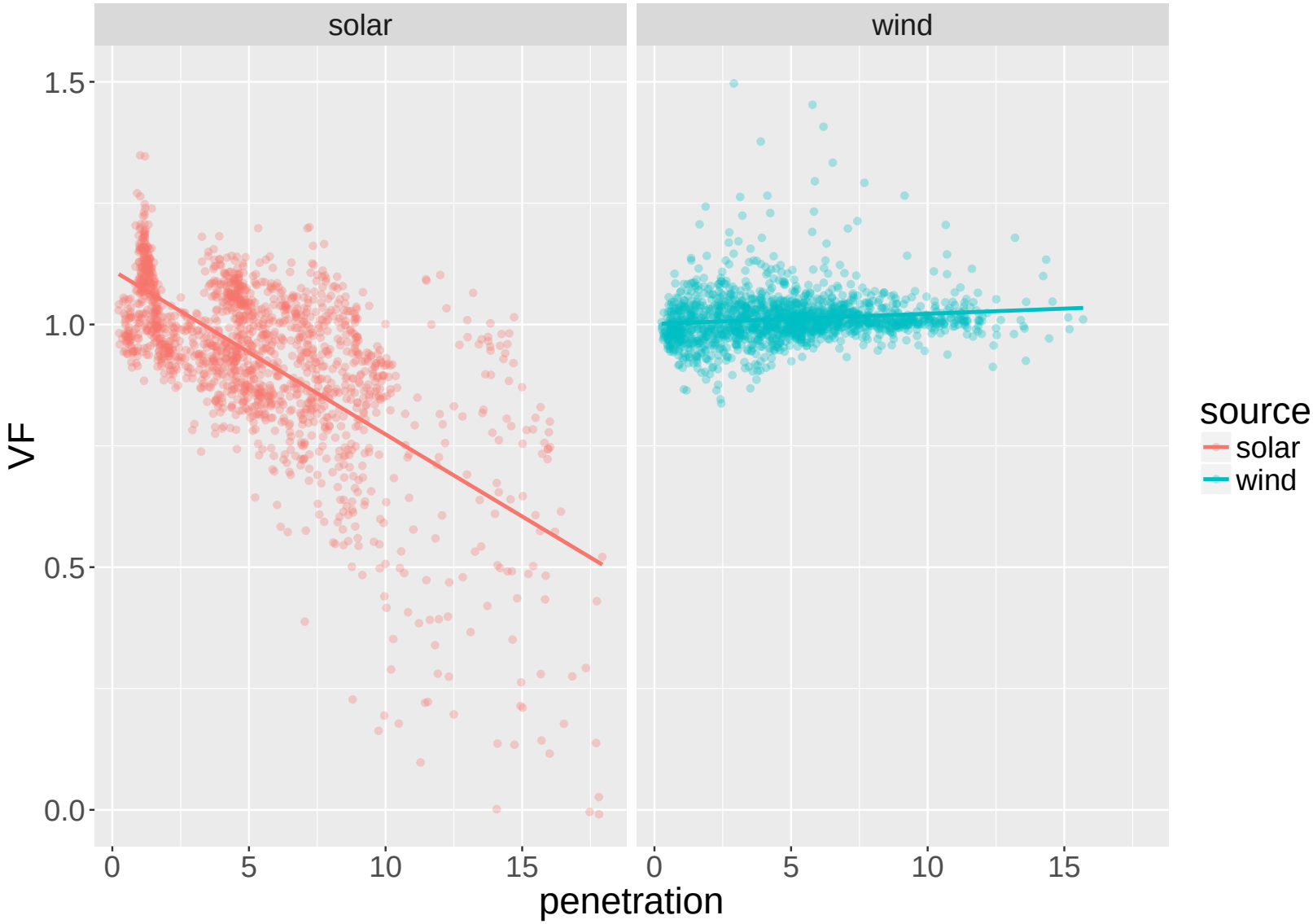

Figure 7: Solar and wind cannibalization effect

Implications for PV competitiveness

Value-adjusted PV LCOE = LCOE/VF

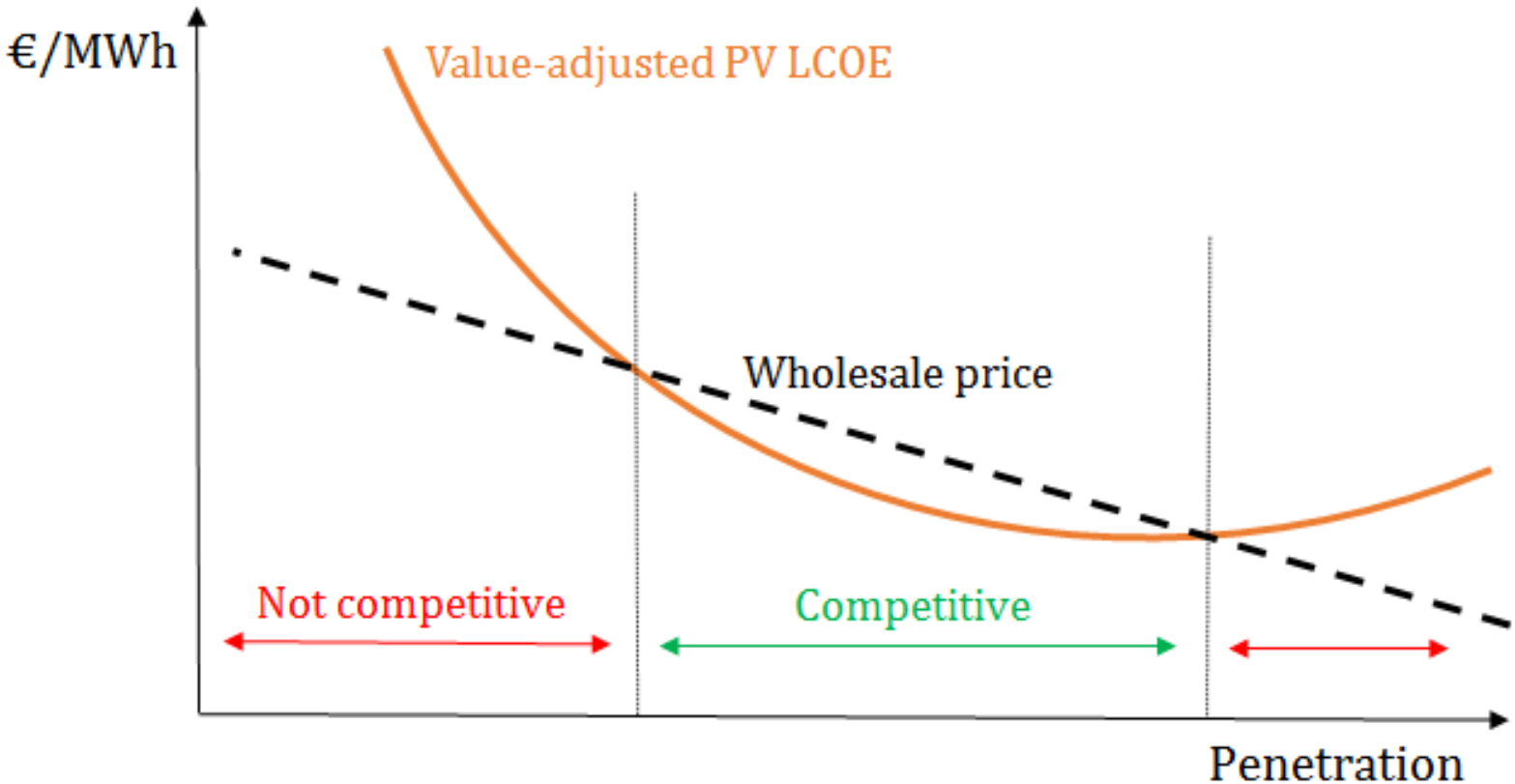

Figure 8: PV cannibalization and competitiveness

Conclusions

- Increasing generation tends to lower the unit revenues of both solar and wind
- Increasing penetration rapidly undermines the value of solar
- Increasing penetration increases the variability of the solar value factor
- The value factor of wind, however, seems to be insensitive to its penetration
- The cannibalization effect could jeopardize PV competitiveness. Mitigation?
  - Market structure
  - Storage options
  - Interconnections

Further research: supply vs. demand-side cannibalization

How to disentangle demand-side (distributed self-consumption PV) from supply-side (centralized utility-scale) cannibalization?

- Estimate demand-side generation from installed capacity
- And then re-estimate the model as

$$VF_d^s = \alpha + \beta_1[(q_d^{ss} + q_d^{sd})/(d_d + q_d^{sd})] + \beta_2[q_d^w/(d_d + q_d^{sd})] + \beta_3 p_d^g + \gamma' D_d + \epsilon_d$$

q_d^{sd} : daily quantity solar demand-side (distributed)

q_d^{ss} : daily quantity solar supply-side (centralized)

Thank you

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Figure 9: that's me

US electricity system

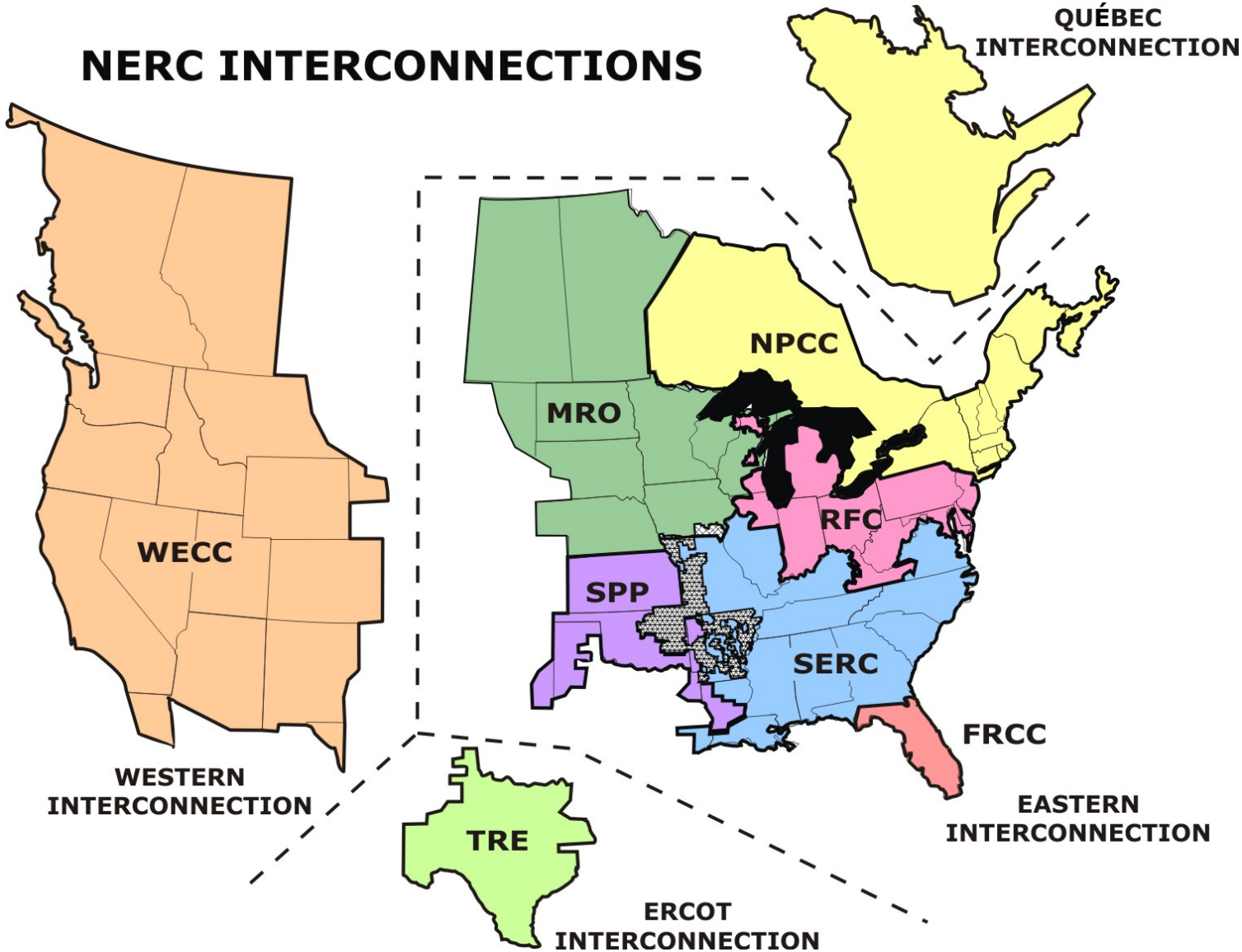

Figure 10: US interconnections

US electricity system

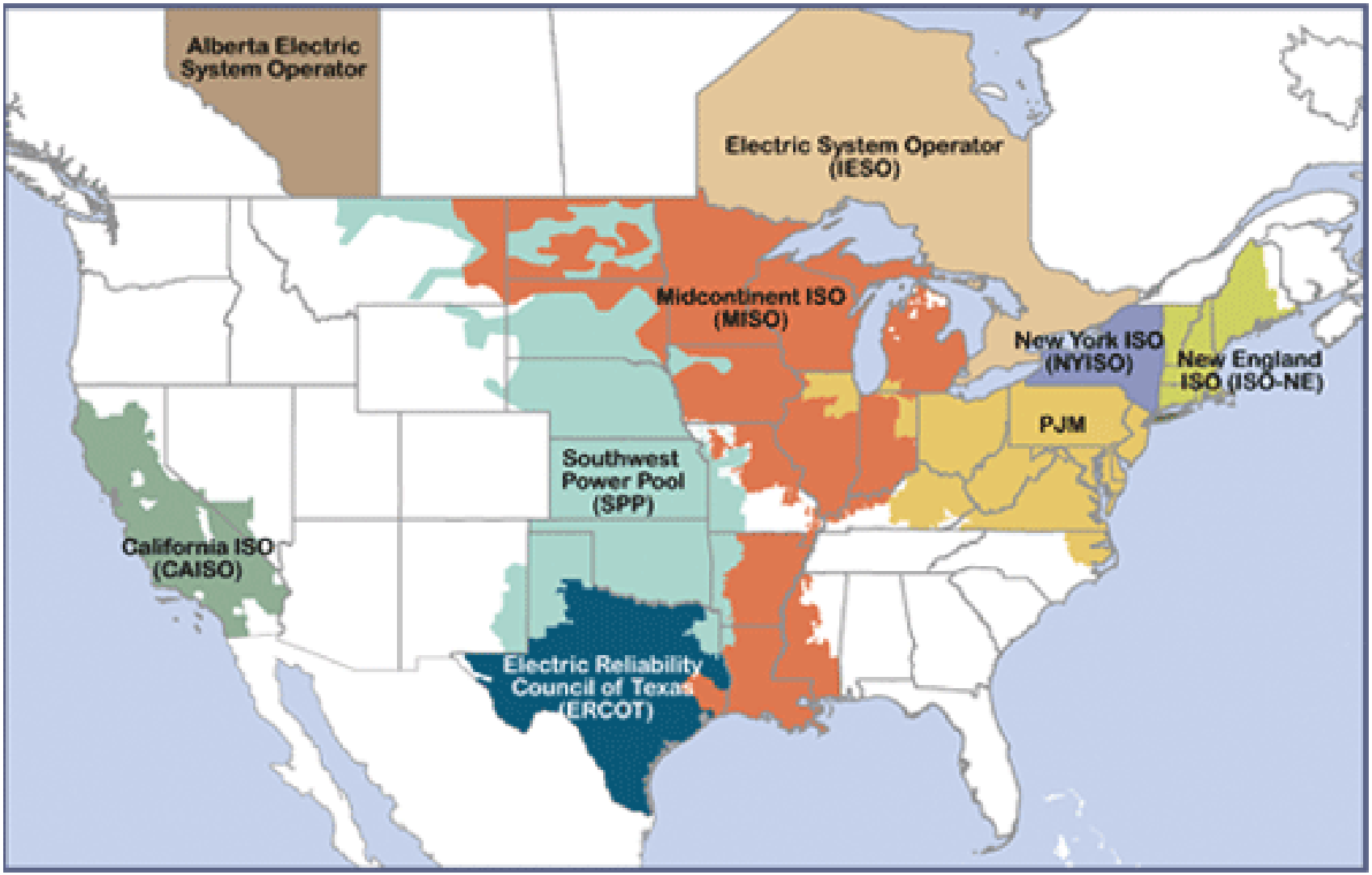

Figure 11: US electricity markets. Source: FERC

Appendix Solar power in California

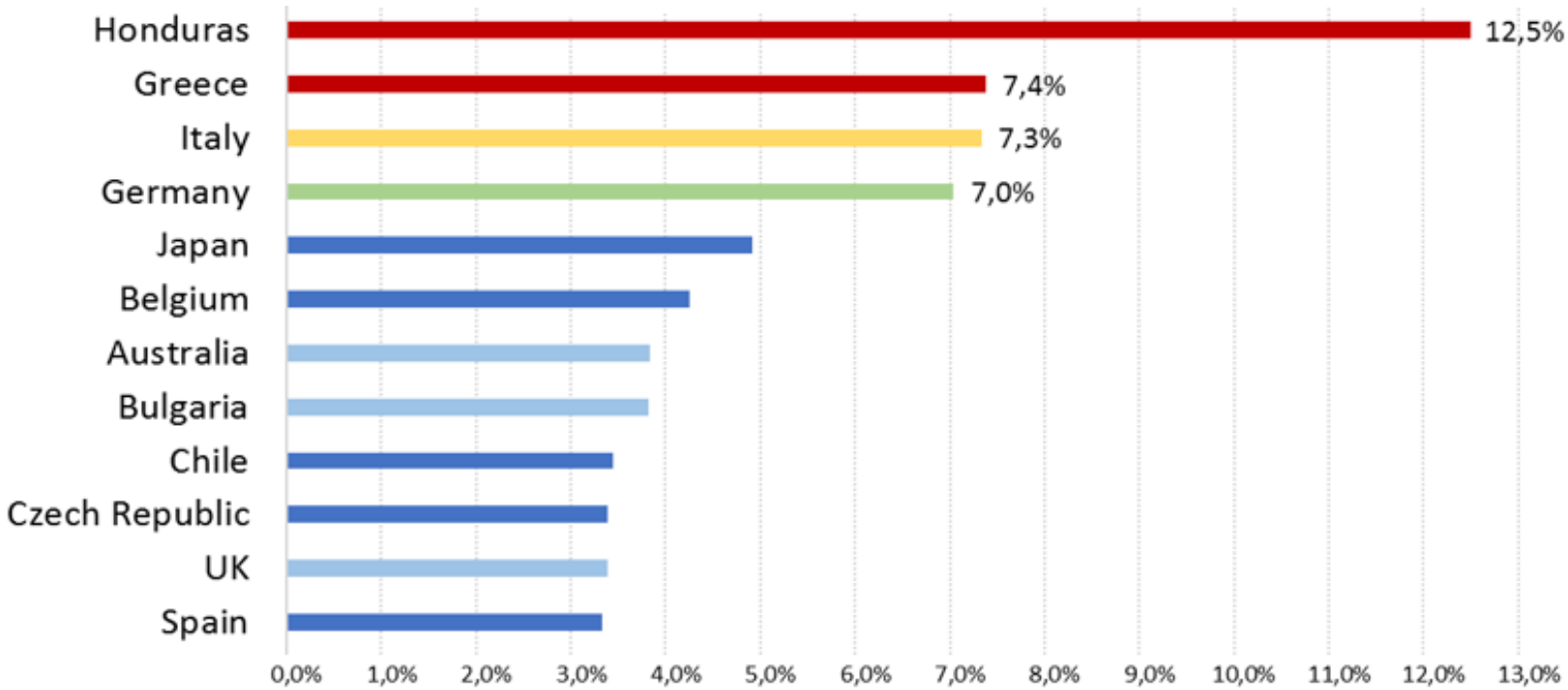

Figure 12: PV penetration. Source: IEA

Appendix Solar power in California

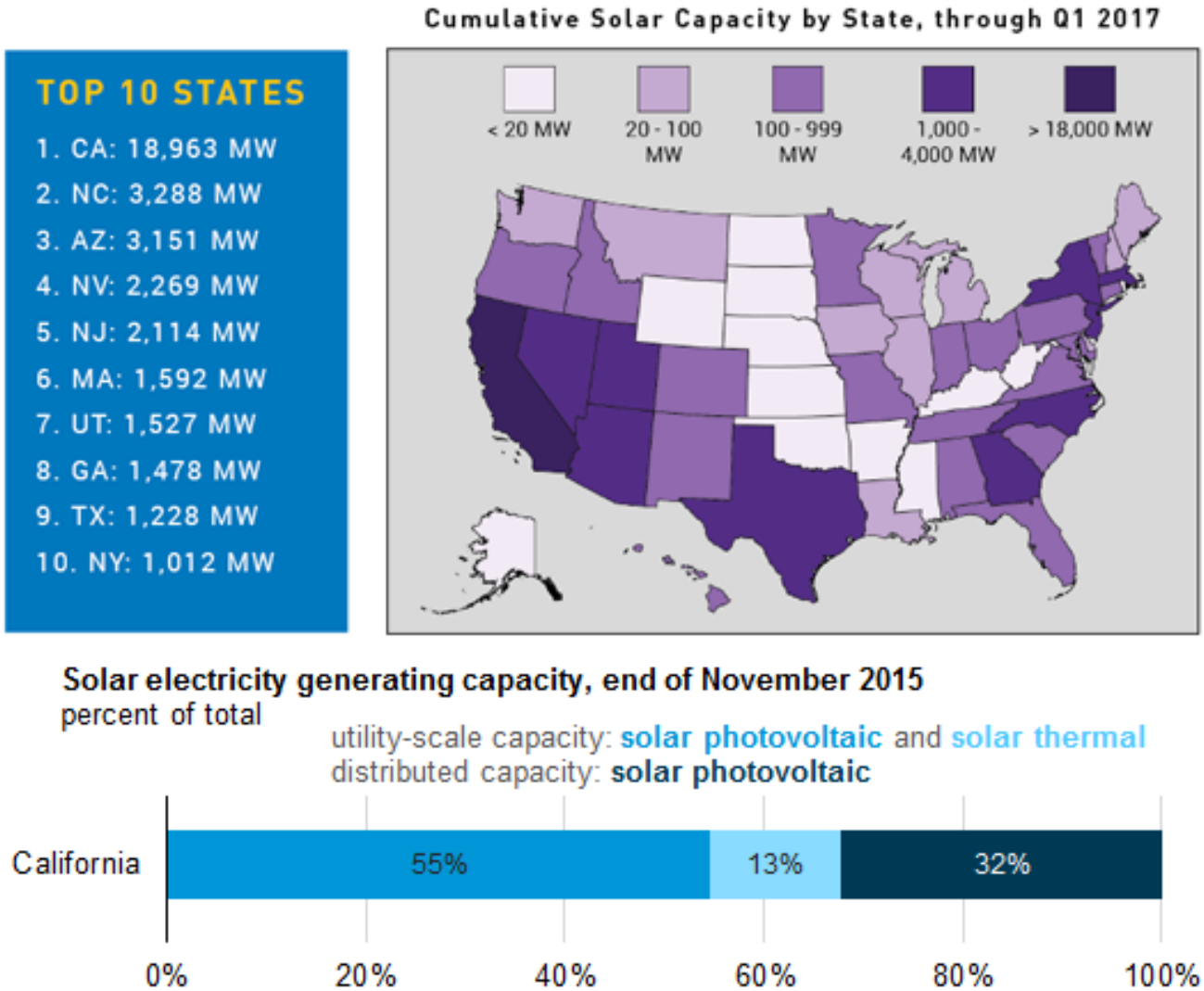

Figure 13: Installed capacity. Source: SEIA and EIA

Appendix: California electricity mix

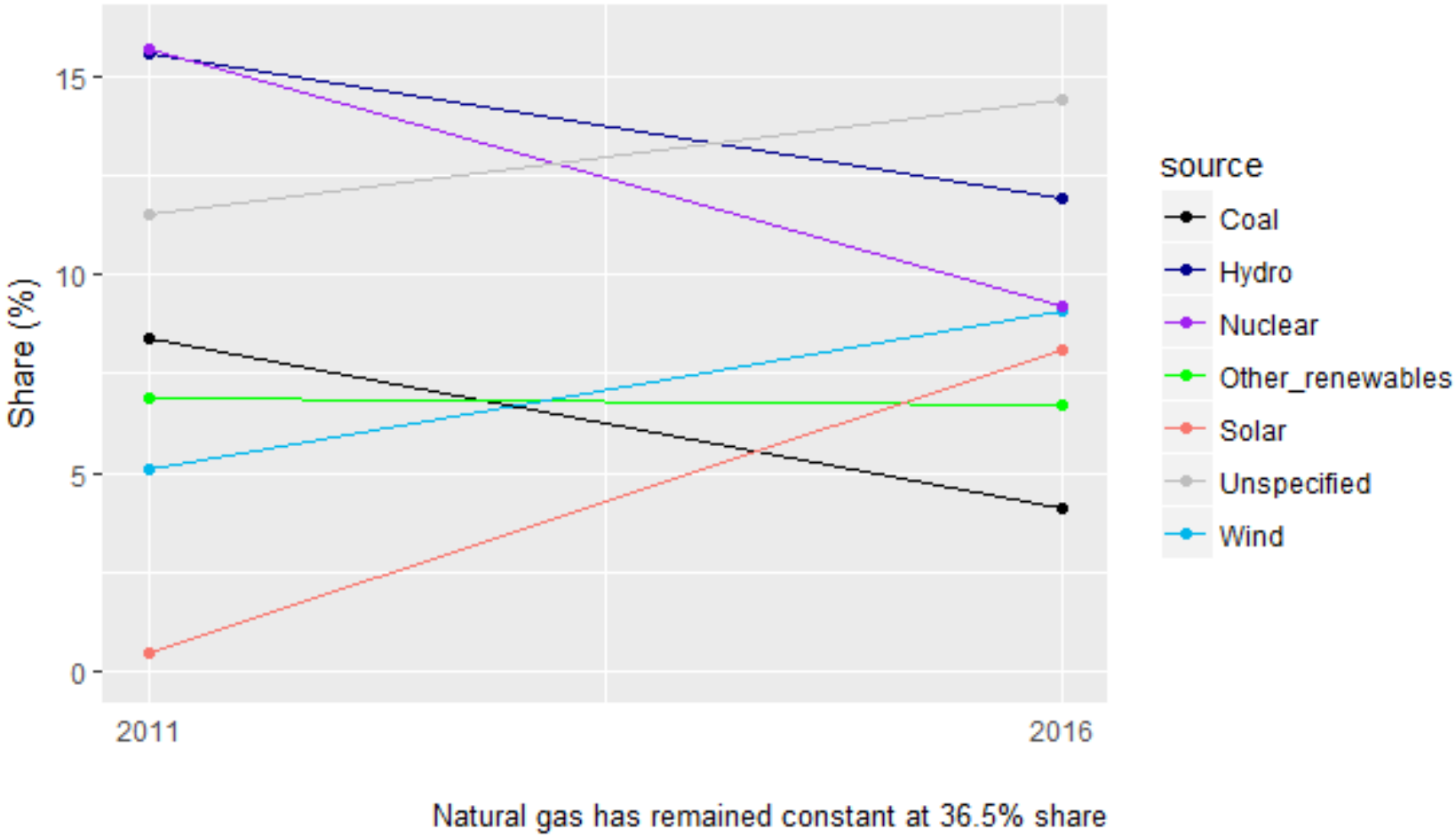

Figure 14: California electriciy mix, 2011 - 2016. Source: IEA

Appendix: Actual vs. forecasted demand

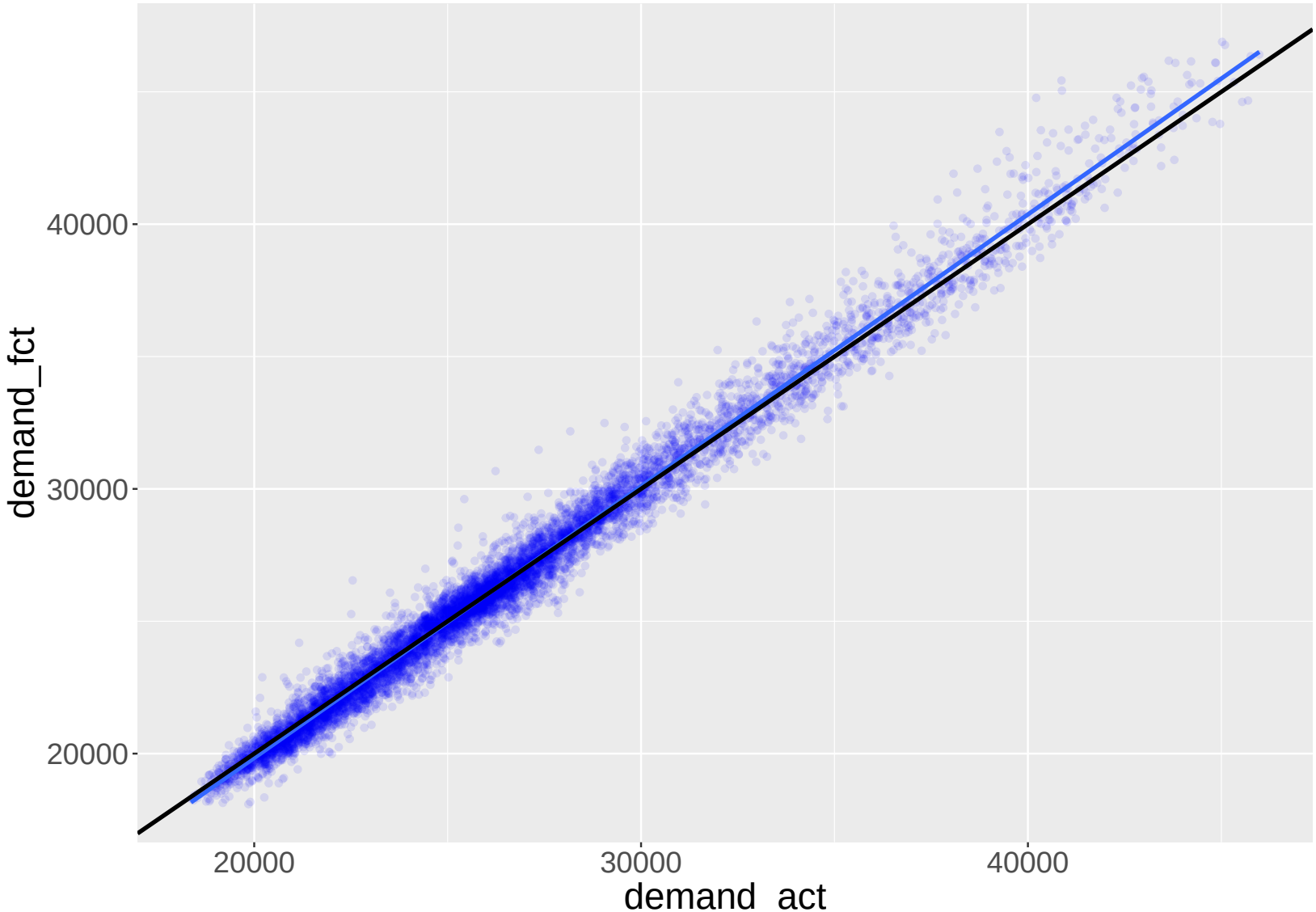

Figure 15: Demand forecast error

Appendix: Actual vs. forecasted generation

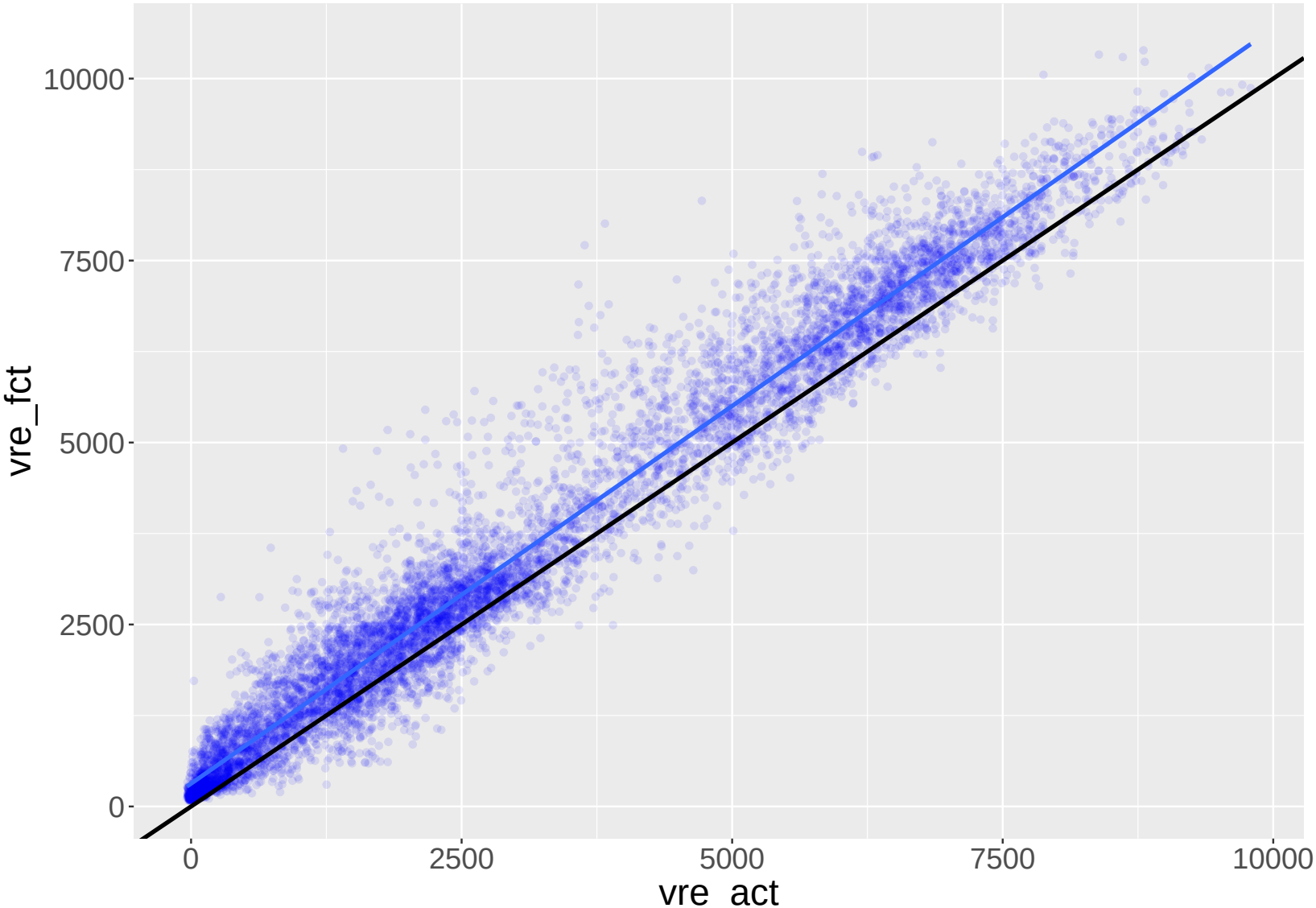

Figure 16: Generation forecast error