



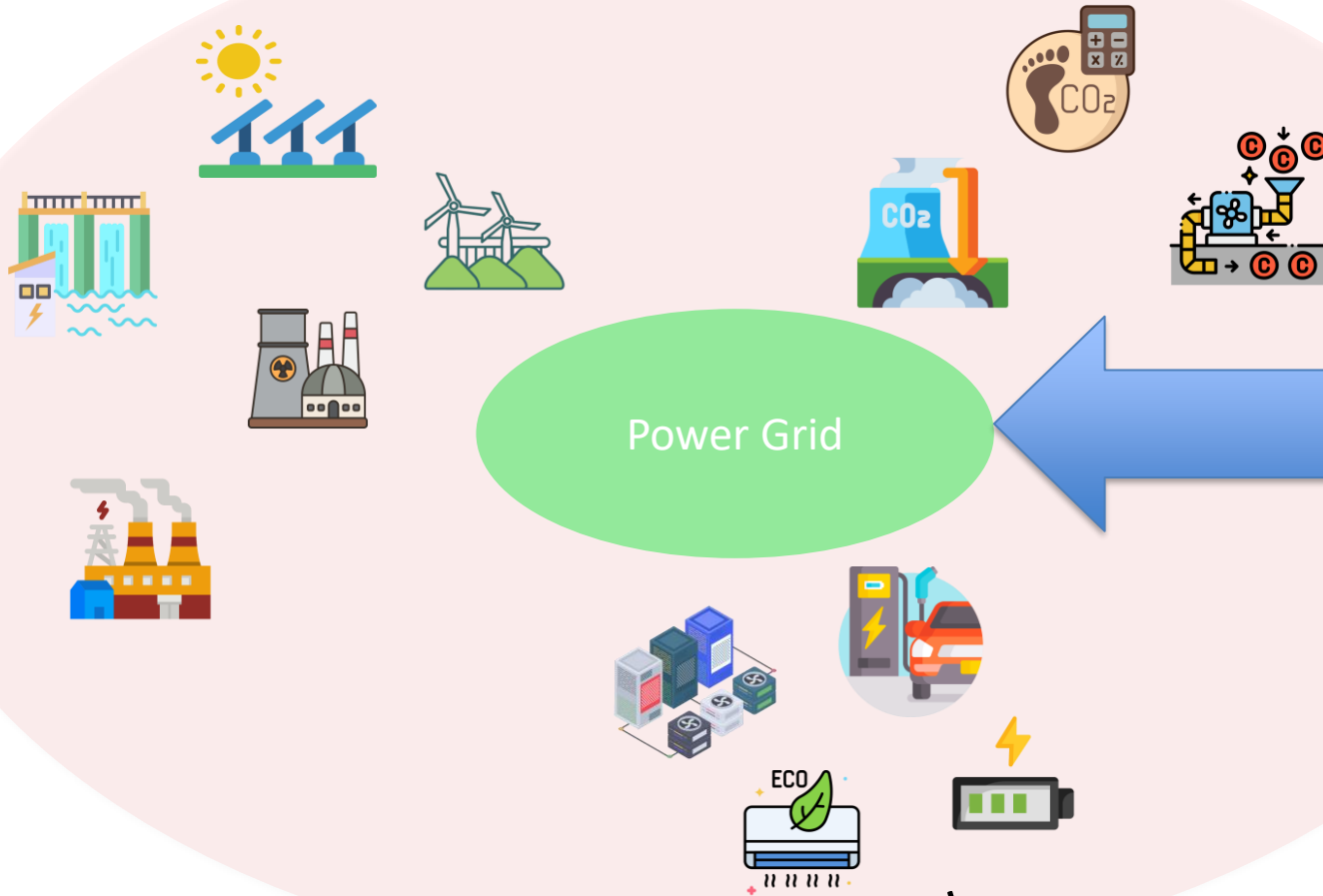
Behavior of Large Cryptocurrency Mining Firms in Electricity Markets: A Texas Econometric Analysis

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09/06/2024

The Power Grid of the 21st Century



Climate Change



Power Grid

Aging electric grid

Stresses the Power Grid



Digitization

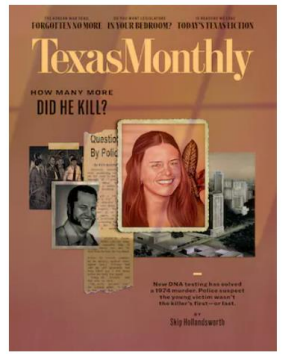
Help the Power Grid



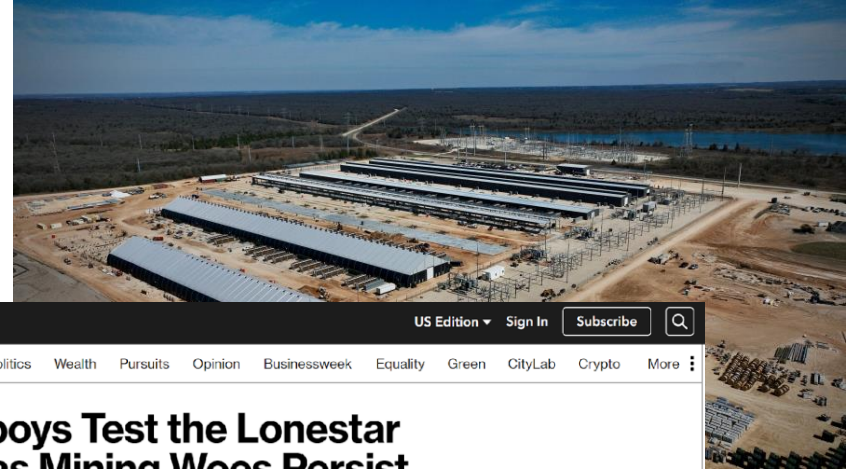
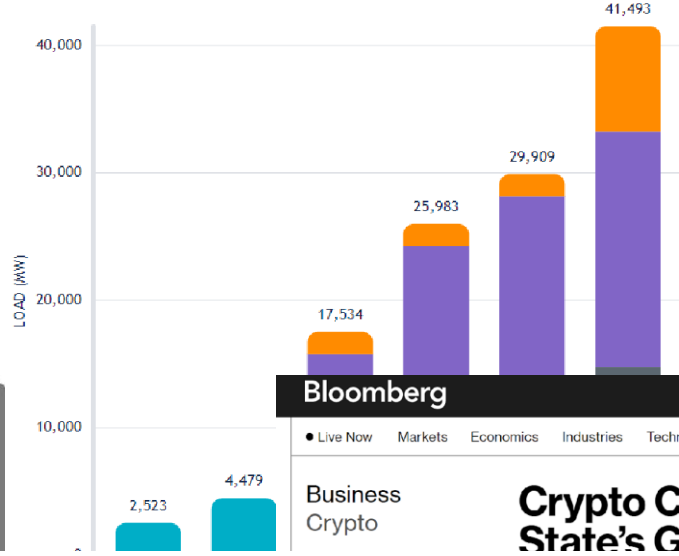
Crypto Mining and Texas Power Grid



- BITCOIN DATA CENTERS
- WIND POWER PLANTS
- SOLAR POWER PLANTS



Actual and Projected LFL Growth 2022-2027



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Business Crypto

Crypto Cowboys Test the Lonestar State's Grid as Mining Woes Persist

their losses are still being lured to Texas despite the state's grid

ENERGY

Bitcoin Miners Could Save the Texas Grid—or Sink It

Our state struggles to serve Texans' r
So why are we welcoming the energy



The Dallas Morning News

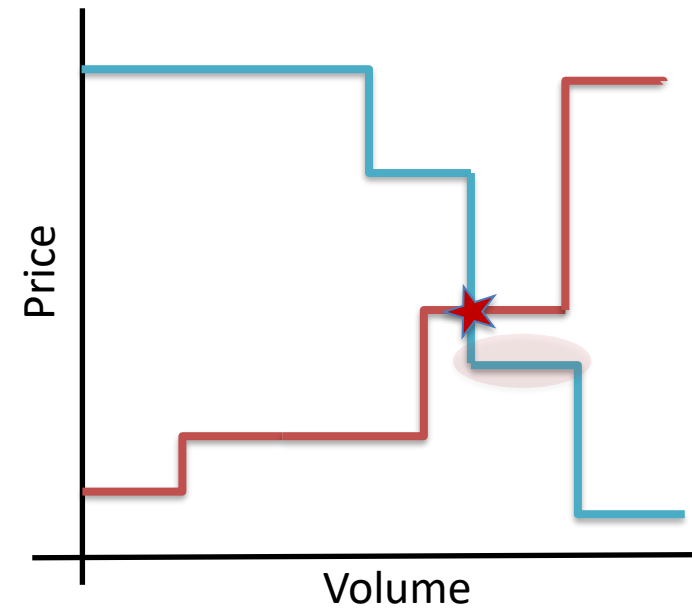
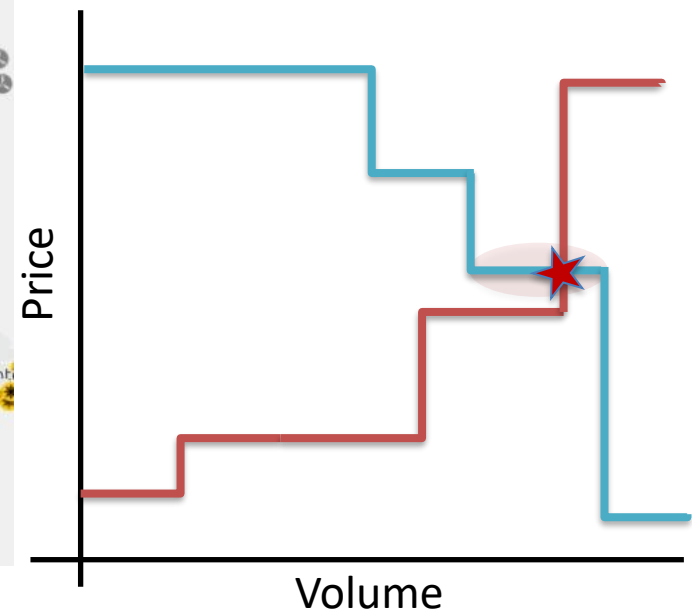
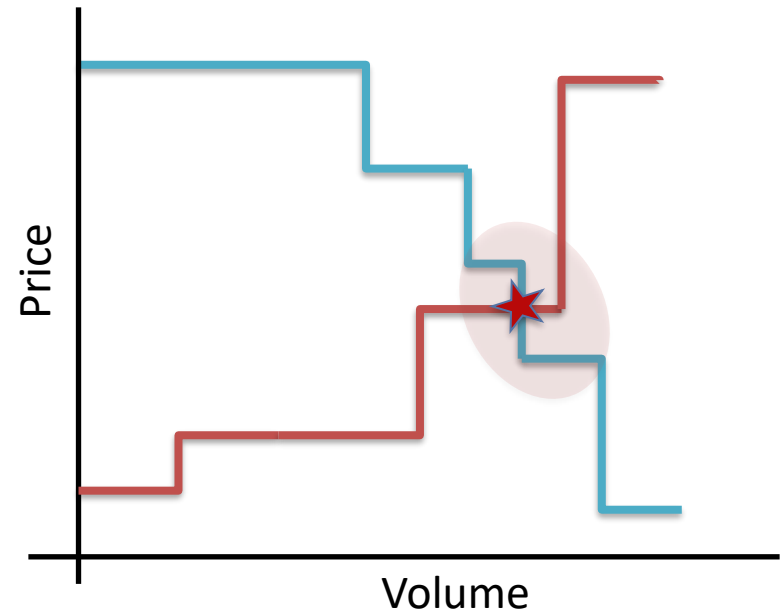
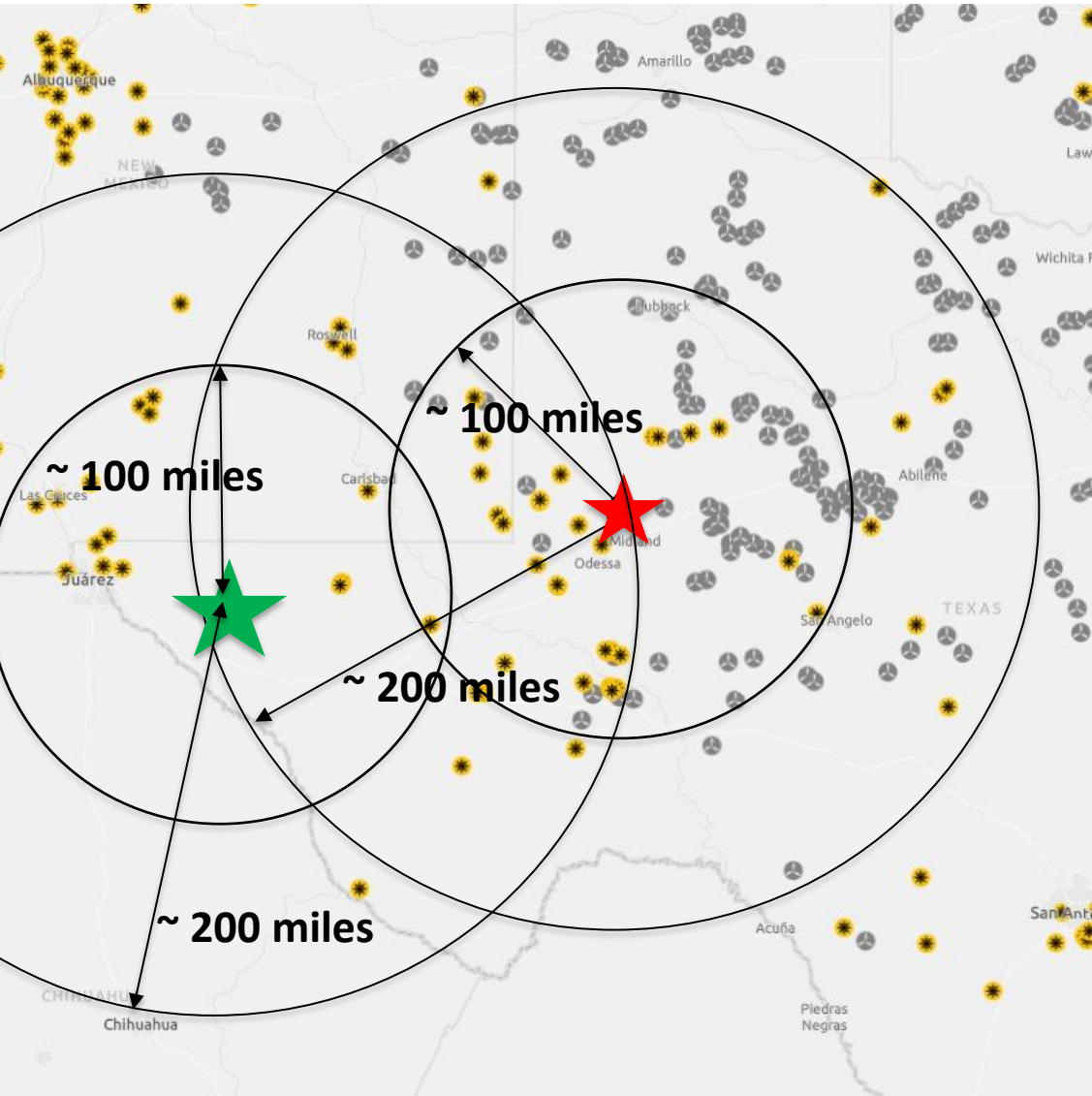
NEWS > POLITICS

Texas ERCOT response to lawmakers' Bitcoin mining concerns still a work in progress

Congressional Democrats are investigating whether mining operations are straining the grid.

sources:
<https://theminermag.com/news/2024-02-29/bitcoin-mining-map-north-america-texas/riot>
<https://x.com/JMellerud/status/1584787940881965057>
https://www.ercot.com/files/docs/2024/05/05/LLI%20Queue%20Status%20Update%20-%202024_5_2.pdf
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<https://www.bloomberg.com/news/articles/2022-11-03/bitcoin-btc-miners-are-still-moving-to-texas-despite-power-grid-issues>
<https://insider.govtech.com/texas/news/texas-ercot-response-to-lawmakers-bitcoin-mining-concerns-a-work-in-progress>

How Possibly Cryptominers Impacting the Power Grid?

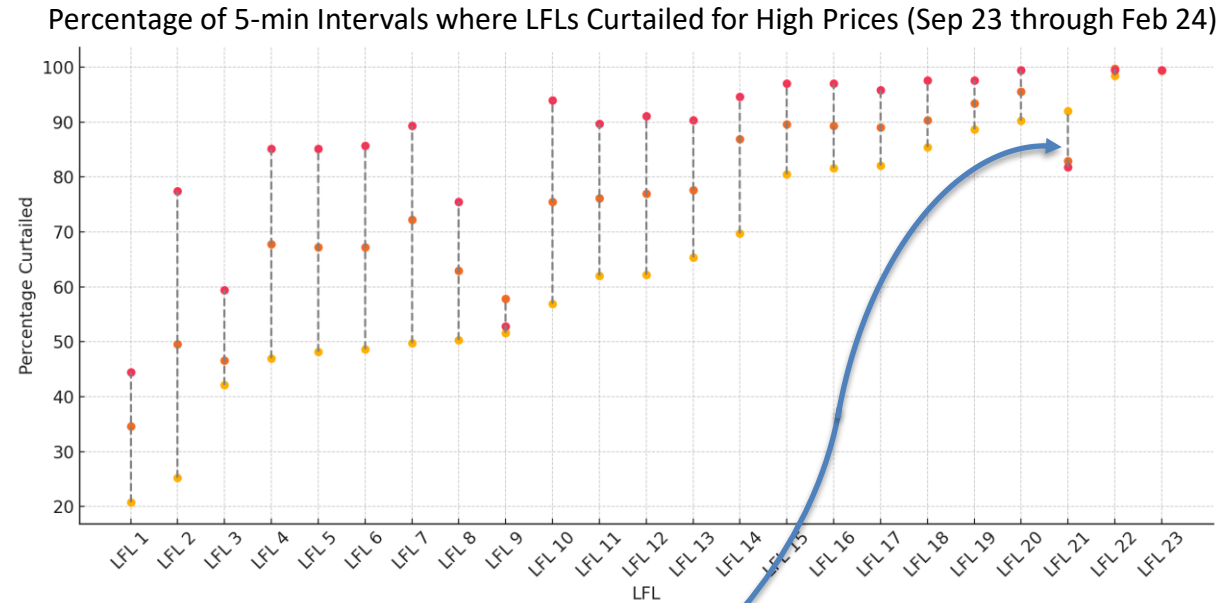


Why does such a Strategic Behavior Matter?



	Cryptocurrency-mining Firms' Response	ERCOT-wide Load Response
Non-summer	-0.17	0.78
Summer	-0.40	0.89

- Percentage curtailed at S21 Strike Price (\$140 - 310/MWh)
- Percentage curtailed at \$500/MWh
- Percentage curtailed at \$1000/MWh



- Responses across facilities are inconsistent
- Miners could be irrational

- ERCOT has to utilize frequency regulation to manage these unexpected variations
- These loads' ramping up or down behavior is often faster than regulation services utilized by ERCOT

Data sources:

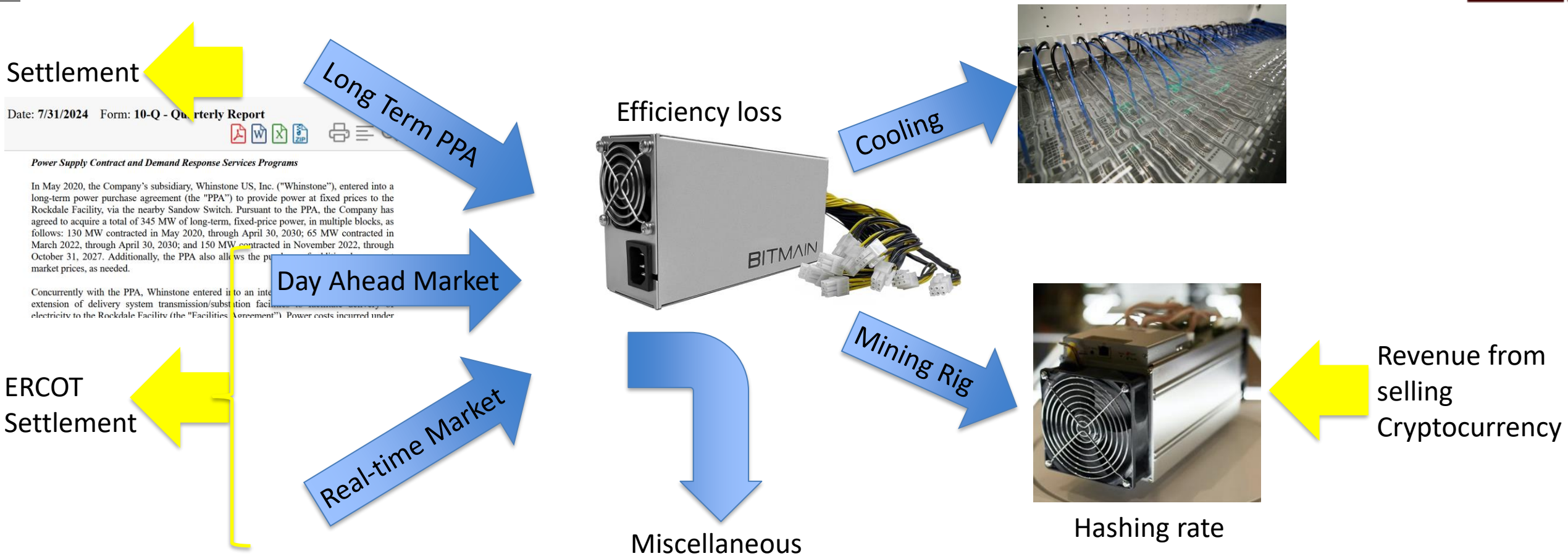
https://www.ercot.com/files/docs/2024/05/05/LLI%20Queue%20Status%20Update%20-%202024_5_2.pdf

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Understanding the behavior of these farms is extremely important for ERCOT to strategically manage these resources

Energy/Cash flow diagram of a typical mining farm



$$E_t^{Farm} = E_t^{PPA} + E_t^{DAM} + E_t^{RTM} = E_t^{Mining} + \psi(E_t^H, T_t)$$

4CP Avoidance



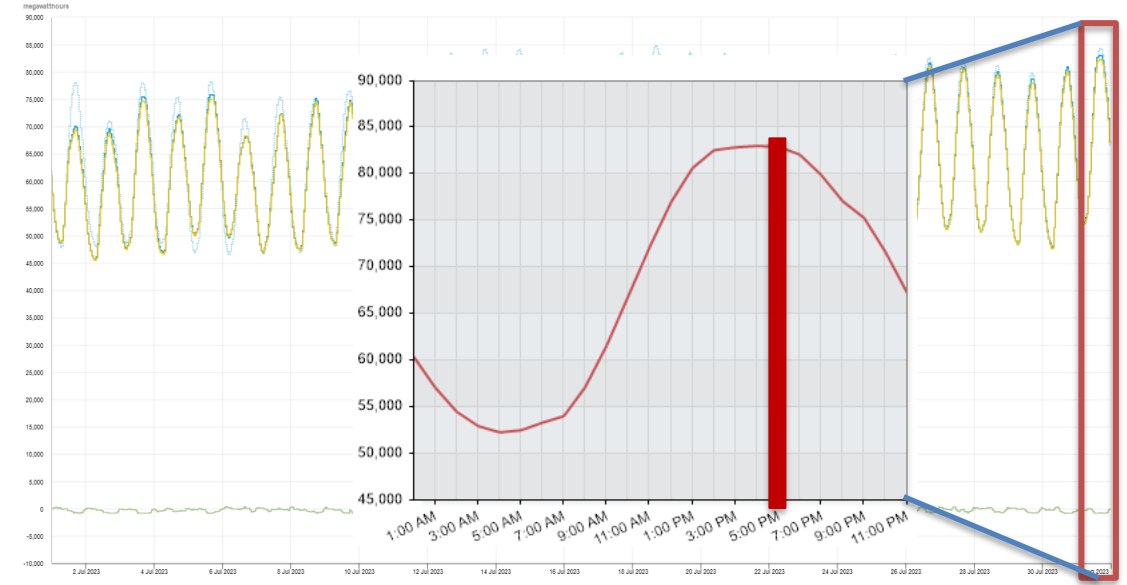
Date: 7/31/2024 Form: 10-Q - Quarterly Report



the Company to remain powered on during the times in which its power is bid into ancillary services, and giving ERCOT the ability to direct the Company to power down the amount of power bid into the program. The Company receives compensation for its participation in ancillary services whether or not the Company is actually called to power down.

The Company also participates in ERCOT's Four Coincident Peak ("4CP") program, which refers to the highest-load settlement intervals in each of the four summer months (June, July, August, and September), during which time, demand for power is typically at its highest across the ERCOT grid. 4CP participants may voluntarily power down operations during these times and in doing so, reduce the electrical load demand on the ERCOT grid. Participants that reduce their load in these peak periods receive credits to transmission costs on future power bills during the subsequent year, reducing overall power costs for the year. **As a result of participation in 4CP in 2023, the Company's transmission charges in its ongoing 2024 monthly power bills are substantially reduced.** The 4CP has an indefinite life.

Under the PPA, the Company may also elect not to utilize its long-term, fixed-price power for its operations, and instead elect to sell that power in exchange for credits against future power costs when there is a benefit to the Company, depending on the spot market price of electricity. The Company's power strategy combines participation in Demand Response Services Programs, participation in 4CP, and sales of power, to attempt to manage operating costs most efficiently.



Tariff for Retail Delivery Service Oncor Electric Delivery Company LLC

6.1.1 Delivery System Charges
Applicable: Entire Certified Service Area
Effective Date: September 1, 2024

Sheet: 6.1
Page 3 of 4
Revision: Forty-Nine

Transmission Cost Recovery Factor (TCRF)

Effective Date	Residential Service (\$/kWh)	Secondary Service		Primary Service			Substation (\$/4CP kW)	Transmission Service (\$/4CP kW)	
		≤ 10 kW (\$/kWh)	> 10 kW (\$/NCP kW)	≤ 10 kW (\$/kWh)	> 10 kW Distribution Line (\$/NCP kW)	> 10 kW Distribution Line (\$/4CP kW)			
Sept. 1, 2024	0.021800	0.018422	4.959012	5.204771	0.009666	5.456689	4.659425	3.232099	4.854456
March 1, 2024	0.016291	0.014368	4.369967	4.874899	0.009247	5.498543	4.396273	2.973098	4.960216

$$4CP \text{ Cost} = TDSP_{Cost} \frac{P_{June}^{firm} + P_{July}^{firm} + P_{August}^{firm} + P_{September}^{firm}}{P_{June}^{System} + P_{July}^{System} + P_{August}^{System} + P_{September}^{System}}$$

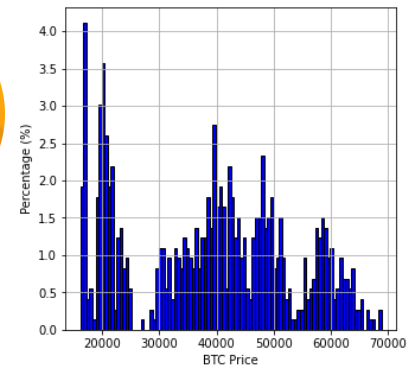
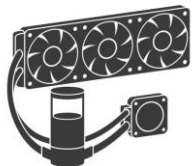
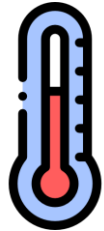
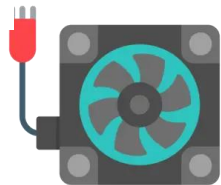
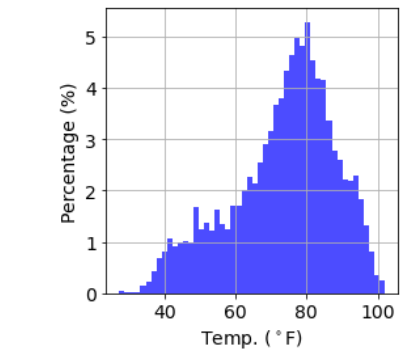
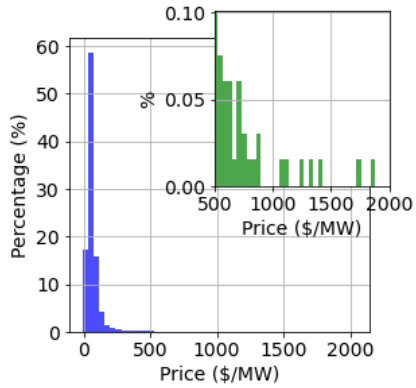
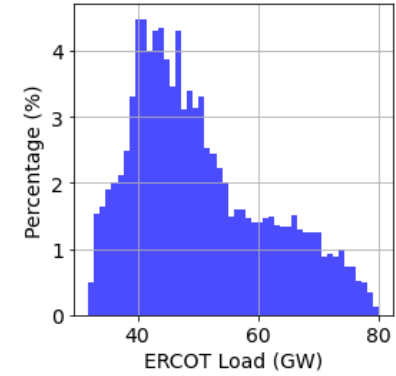
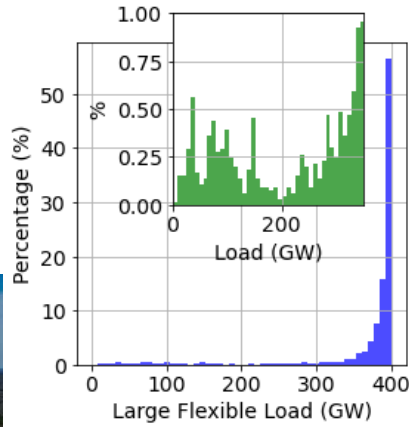
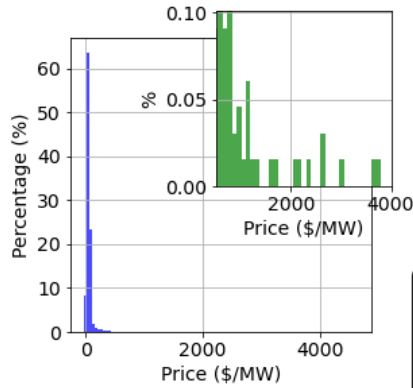
500 MW firm



\$29.76M annually

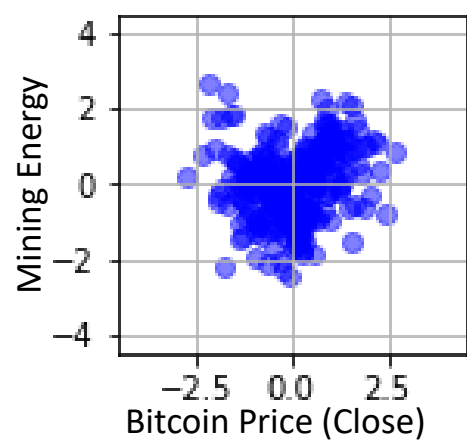
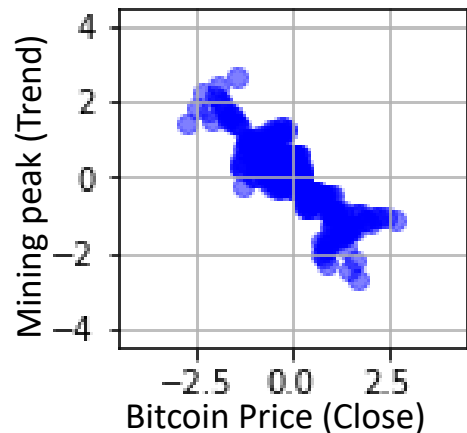
sources:
Icons from Flaticons.com
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<https://www.eia.gov/electricity/gridmonitor/dashboard/custom/pending>
<http://www.energyonline.com/Data/GenericData.aspx?DataId=5&ERCOT> Actual Load

Firm Energy Consumption Signatures



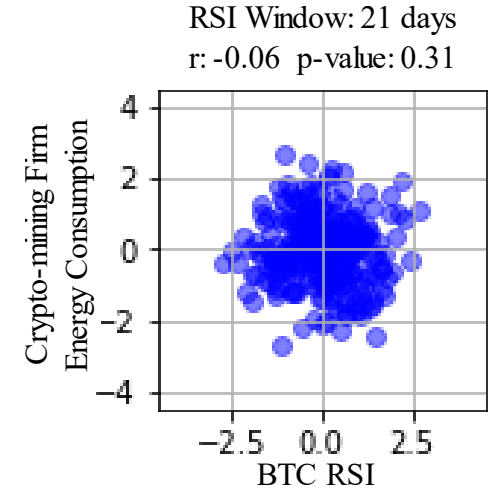
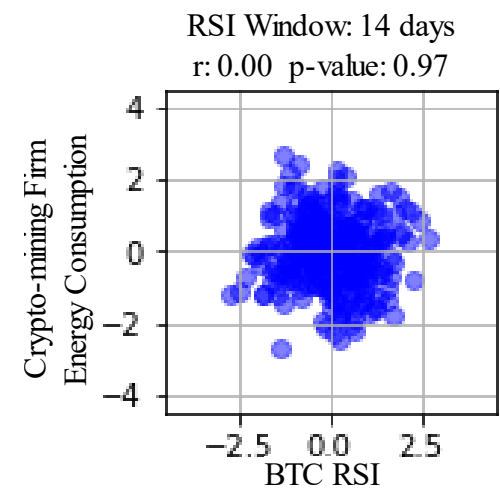
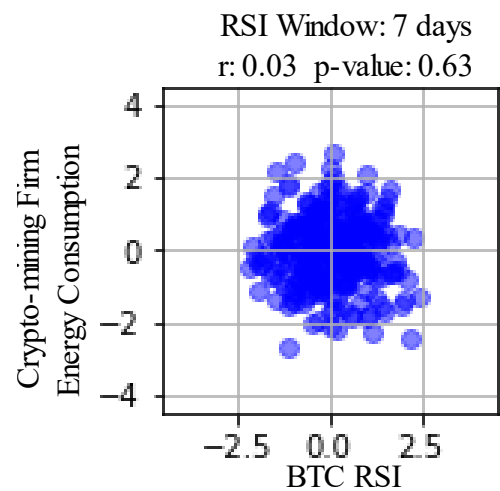
sources:
Icons from Flaticons.com
<https://www.riotplatforms.com/>

Bitcoin vs Crypto-miners Energy Consumption



RSI: A momentum oscillator that measures the speed and change of price movements, used to identify overbought or oversold conditions

$$RSI = 100 - \frac{100}{1 + \frac{\text{Average Loss}}{\text{Average Gain}}}$$



Date: 7/31/2024 Form: 10-Q - Quarterly Report
The following tables present additional information about our own Bitcoin mining activities, including Bitcoin production and sales of the Bitcoin mined:

	Quantity	Amounts
Balance as of January 1, 2024	7,362	\$311,178
Revenue recognized from Bitcoin mined	2,208	127,160
Change in Bitcoin receivable	10	249
Proceeds from sale of Bitcoin	(212)	(9,518)
Exchange of Bitcoin for employee compensation	(34)	(1,692)
Change in fair value of Bitcoin	—	157,677
Balance as of June 30, 2024	9,334	\$585,054

sources: <https://www.riotplatforms.com/>

BTC Prices do not dictate short term energy consumptions

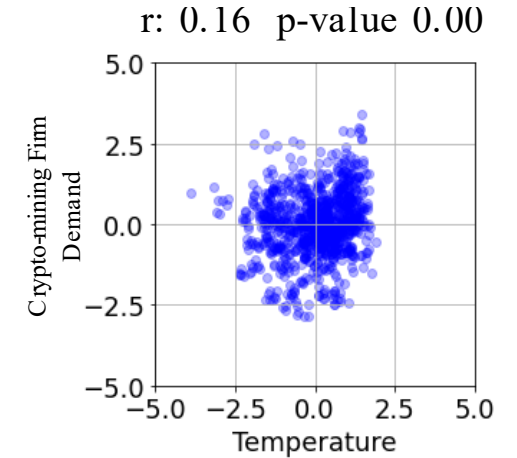
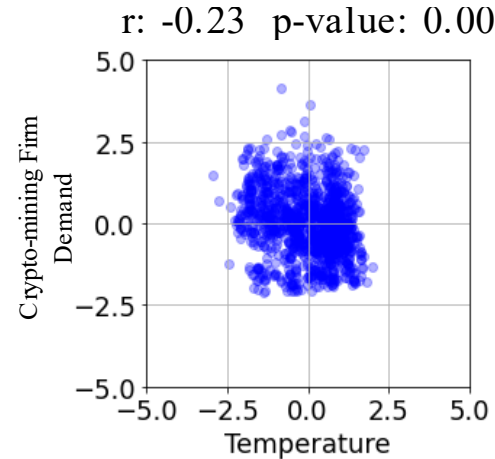
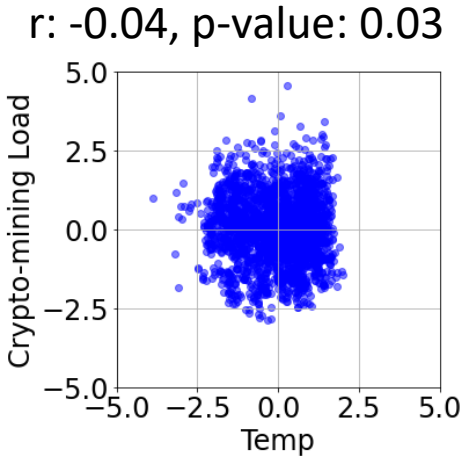
Cooling Requirements vs Energy Consumption



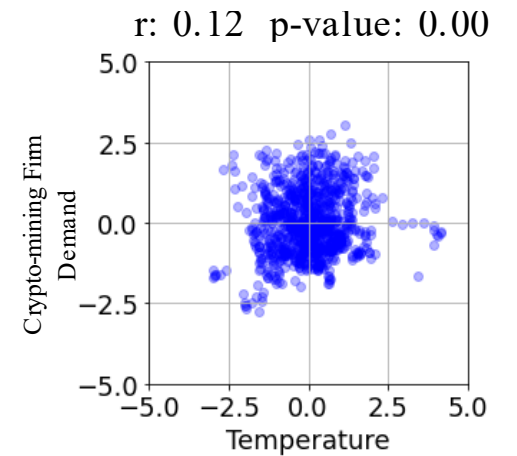
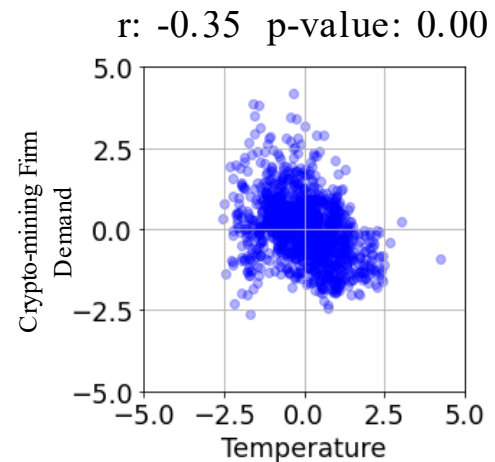
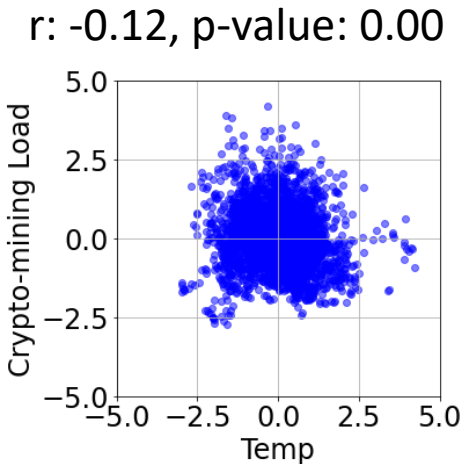
Cooling load due to ventilation

$$Q_{cooling} = \dot{m} \times C_p \times (T_{outside} - T_{inside})$$

Non-summer



Summer



Entire data

10 AM – 8 PM

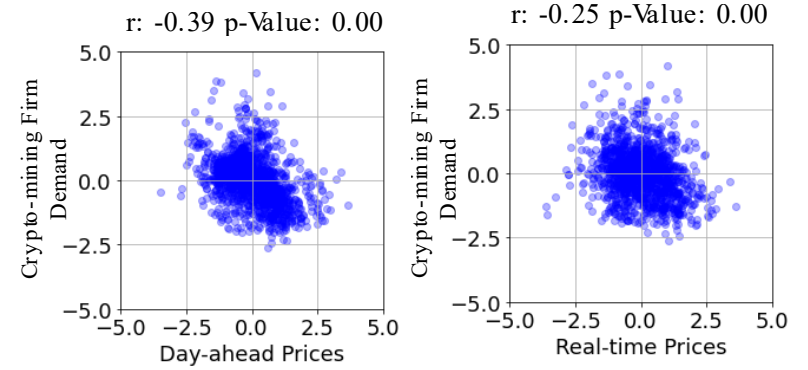
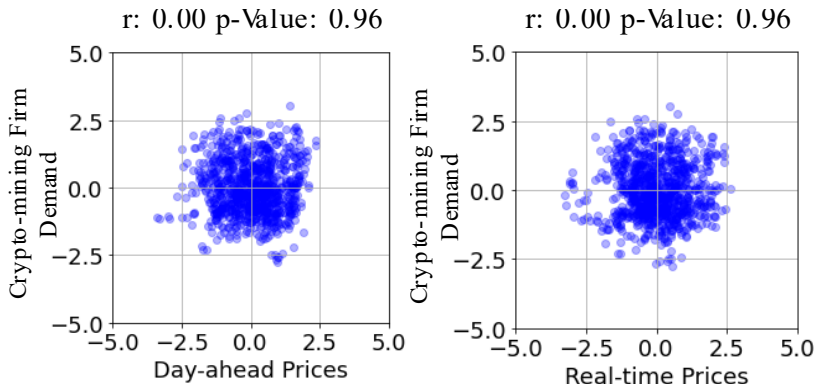
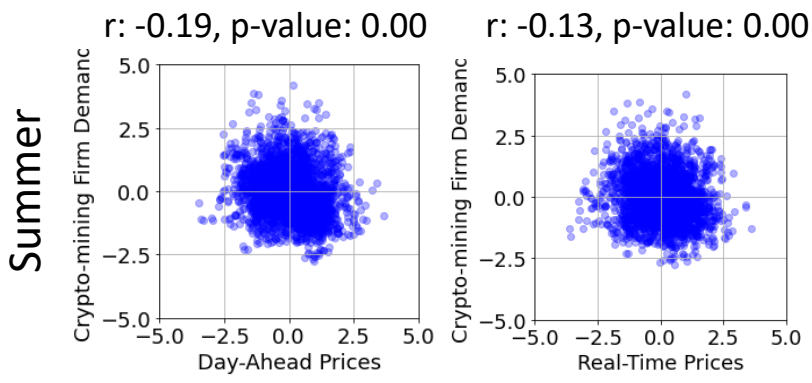
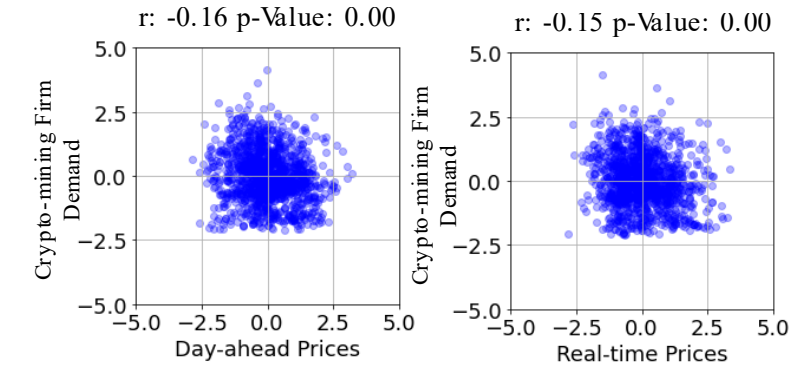
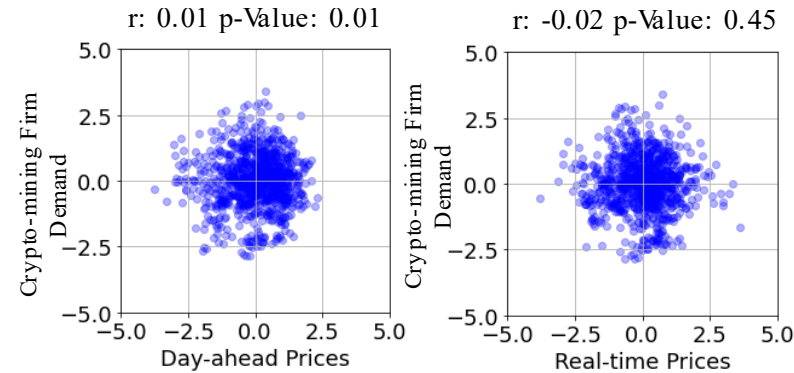
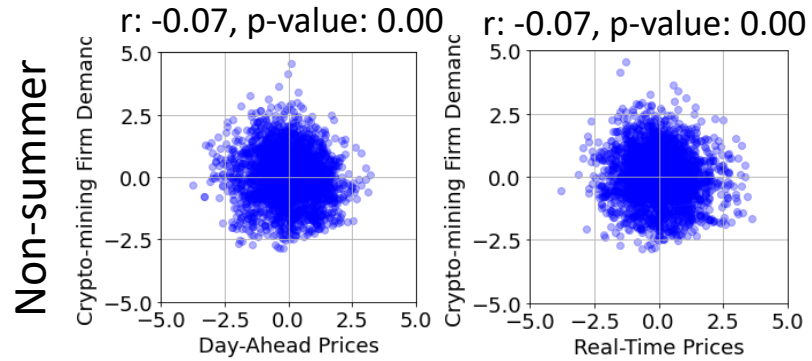
11 PM – 6 AM

Electricity Prices vs Energy Consumption



Miners are profit maximizers:

$$\max_{\forall t} \sum (\pi_t^B k^B E_t^H - \pi_t^R E_t^R - \pi_t^D E_t^D + \gamma(E_t^M))$$



Entire data

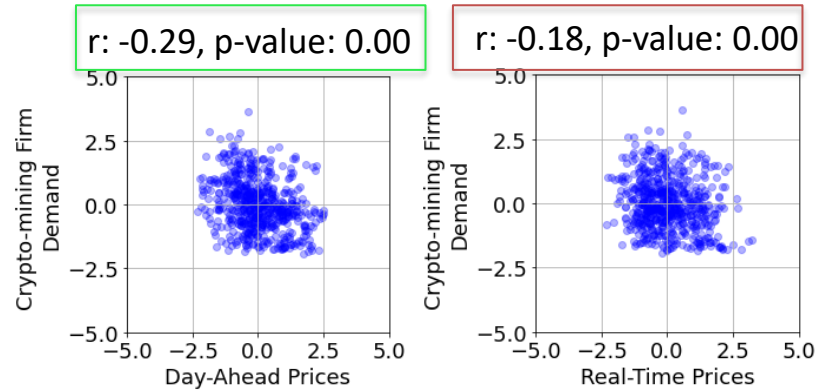
11 PM – 6 AM

10 AM – 8 PM

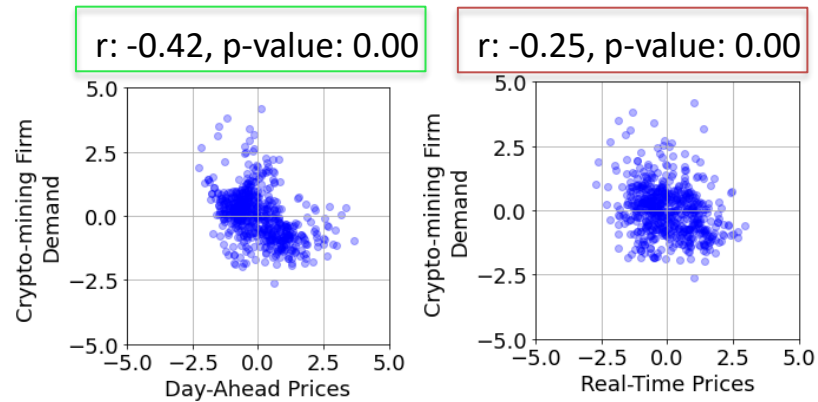
Electricity Prices vs Energy Consumption



Non-summer



Summer



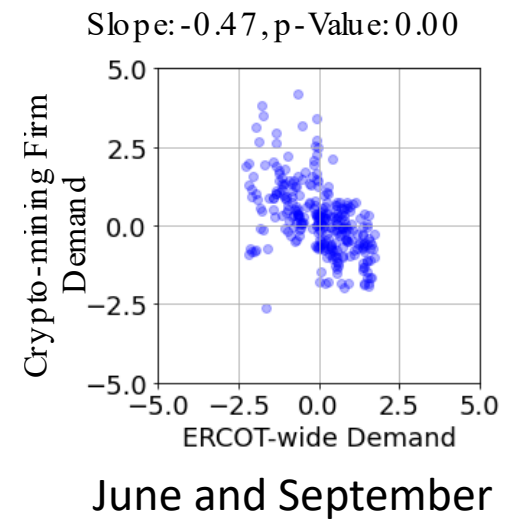
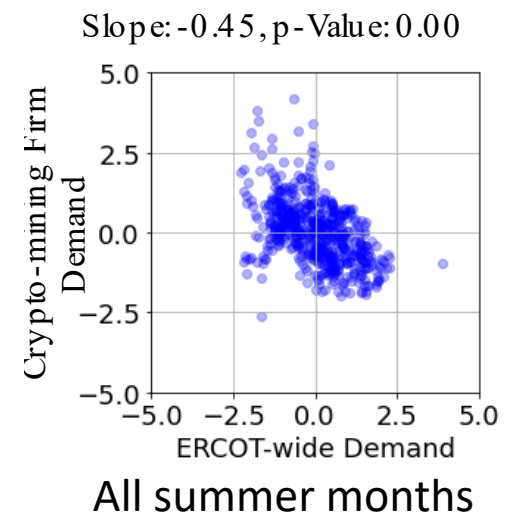
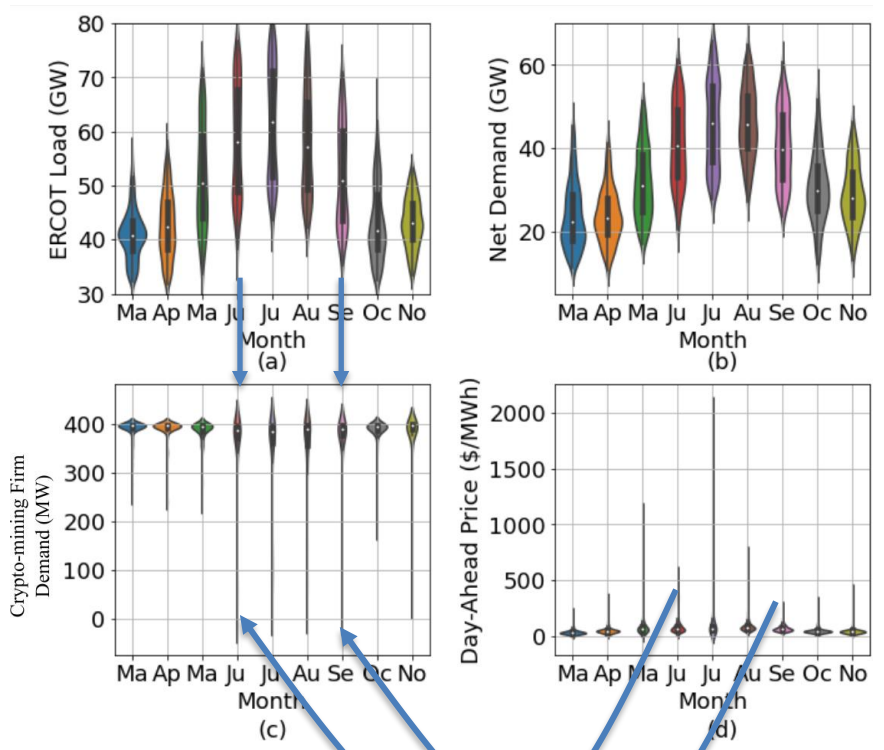
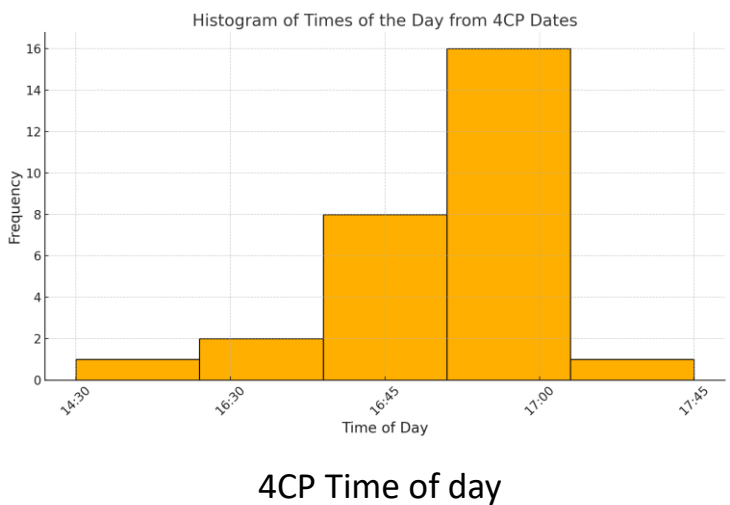
3 PM – 7 PM



How Could Miners hedge against 4CP?

Miners are profit maximizers:

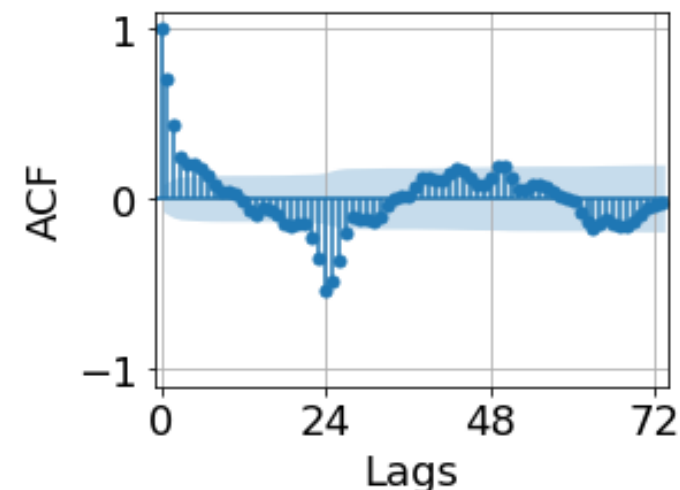
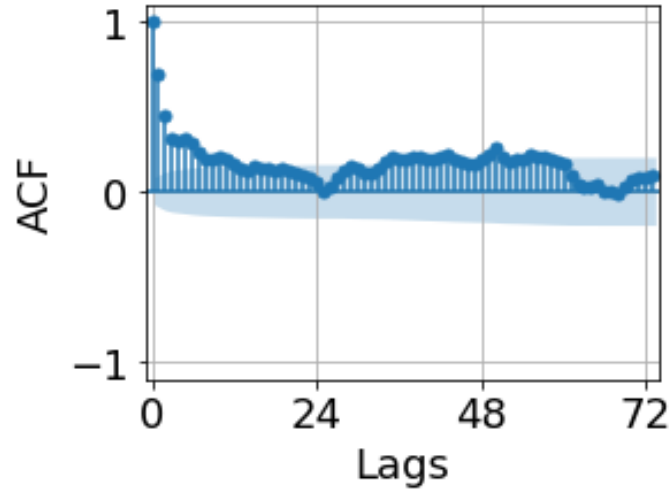
$$\max \sum_{\forall t} (\pi_t^B k^B E_t^H - \pi_t^R E_t^R - \pi_t^D E_t^D + \gamma(E_t^M))$$



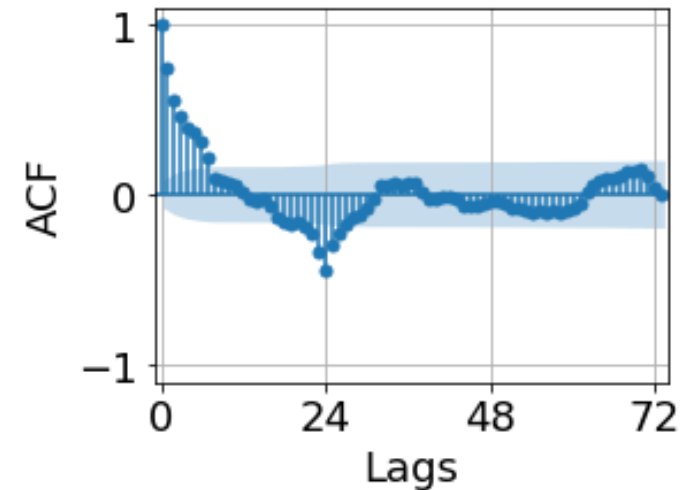
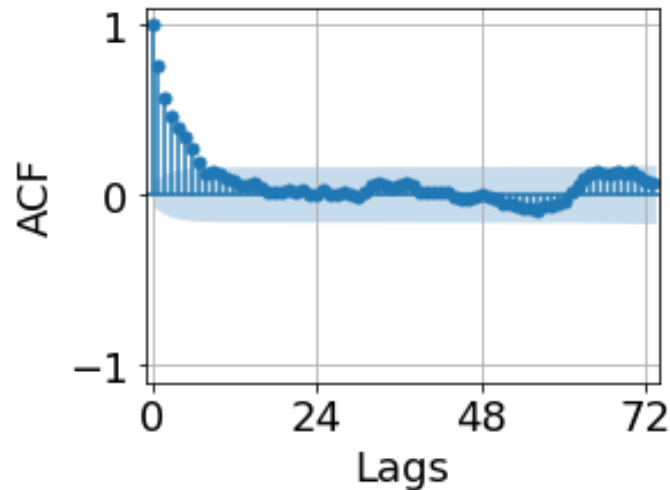
How Miner's Past Responses Affect Current Response

$$\Phi(B^S)\phi(B)\nabla^d\nabla_s^D y_t = \Theta(B^S)\theta(B)\epsilon_t$$

Non-summer



Summer



Historical data

Seasonally differenced data



AR-X Model

Empirical Model



Non-summer

$$E_t^{M,ns} = N^{-1} \left(\psi^{ns} T_t \right. \\ \left. + \mathbb{I}^d(t) \left(\sum_{\forall n \geq 0} \delta_n^{D,ns} \pi_{t-n}^D + \sum_{\forall n \geq 1} \rho_n^{D,ns} \pi_{t-n}^R \right) + \mathbb{I}^P(t) \left(\sum_{\forall n \geq 0} \delta_n^{P,ns} \pi_{t-n}^D + \sum_{\forall n \geq 1} \rho_n^{P,ns} \pi_{t-n}^R \right) \right. \\ \left. + \text{ARMA}^{ns}(p, d, q)(P, D, Q, [24]) \right)$$

Summer

$$E_t^{M,s} = N^{-1} \left(\psi^s T_t \right. \\ \left. + \mathbb{I}^d(t) \left(\sum_{\forall n \geq 0} \delta_n^{D,s} \pi_{t-n}^D + \sum_{\forall n \geq 1} \rho_n^{D,s} \pi_{t-n}^R \right) + \mathbb{I}^P(t) \left(\sum_{\forall n \geq 0} \delta_n^{P,s} \pi_{t-n}^D + \sum_{\forall n \geq 1} \rho_n^{P,s} \pi_{t-n}^R \right) \right. \\ \left. + \mathbb{I}^P(t) \sum_{\forall n \geq 1} \gamma_n L_{t-n} \right. \\ \left. + \text{ARMA}^s(p, d, q)(P, D, Q, [24]) \right)$$

Disclaimers

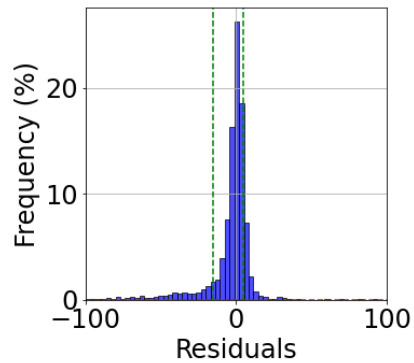


- The model is based on the current understanding of physical processes, and likely would change with intricate details of the miners
- Relationships between these factors are non-trivial and require careful examination over specific time periods
- Focused on consumption patterns rather than market bidding strategies (not enough data)
- The ARMA process is used to model the variance unexplained by the regression model
- The goal is to perform multiple linear regressions to systematically extract the influence of regressors and perform regression based on the residuals from the previous step

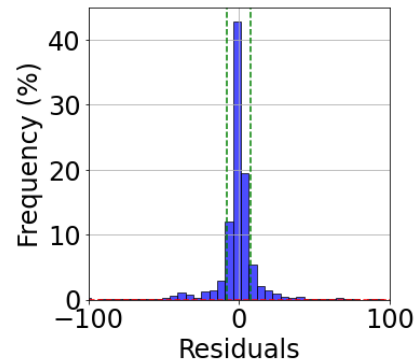
Non-Summer Model



$$E_t^{M,ns} = N^{-1} (0.14T_t) + \mathbb{I}^d(t) (-0.08\pi_{t-48}^D - 0.19\pi_{t-1}^R - 0.11\pi_{t-24}^R) + \mathbb{I}^p(t) (-0.16\pi_{t-1}^D - 0.29\pi_{t-3}^R) + \text{ARMA}^{ns}(1, 0, 0)(1, 1, 0, [24])$$

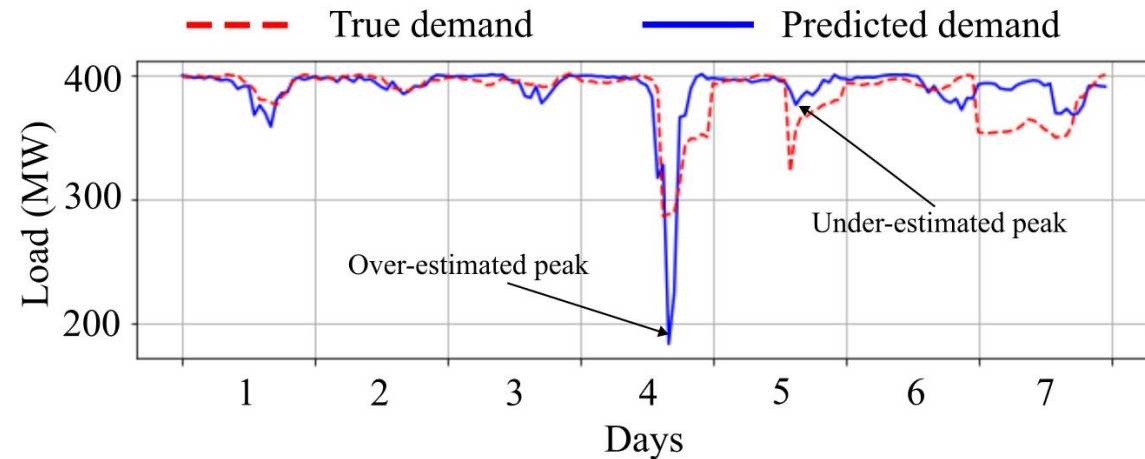


Regression alone



Regression + ARIMA

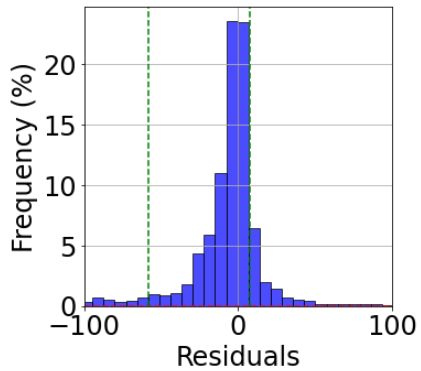
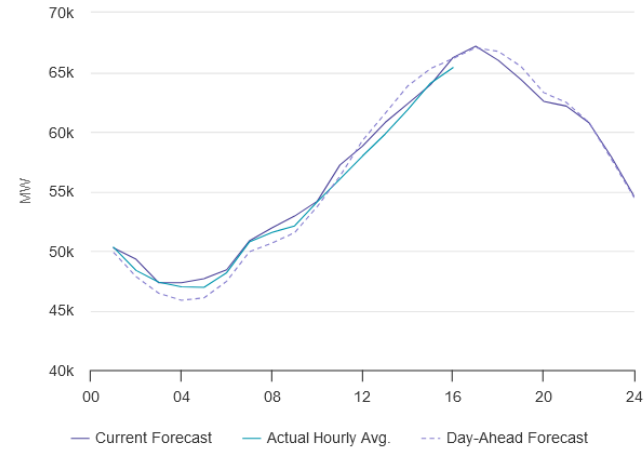
Outlier removed $R^2 = 0.77$



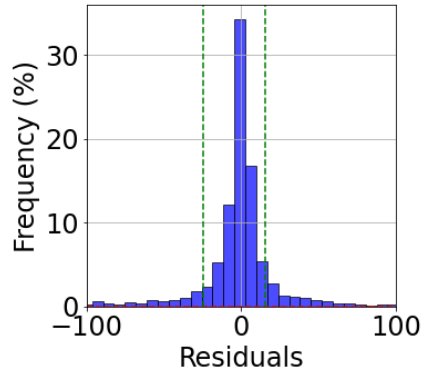
Summer Model



$$E_t^{M,s} = N^{-1} (0.12T_t + \mathbb{I}^d(t) (-0.40\pi_t^D + 0.09\pi_{t-72}^R) + \mathbb{I}^p(t) (-0.13\pi_{t-1}^R) + \mathbb{I}^p(t) (-0.89L_{t-24} + 0.39L_{t-48}) + \text{ARMA}^{ns}(1, 0, 0)(1, 1, 1, [24]))$$

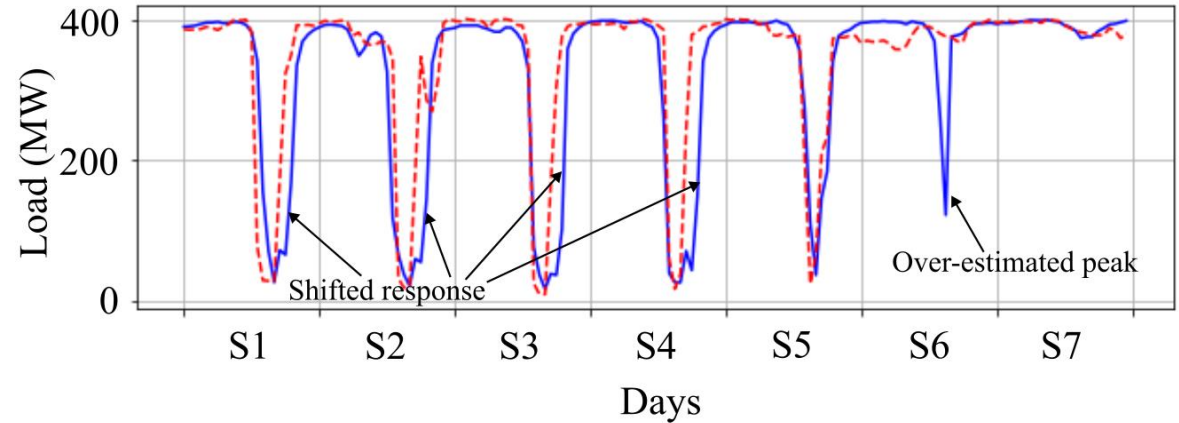


Regression alone



Regression + ARIMA

Outlier removed $R^2 = 0.98$



Summary



- Model accuracy and transferability
- Interaction among multiple mining firms and impacts on the Texas grid
- How do we harvest flexibility of these resources for better planning/operation of the power grid, especially in the climate change scenarios

Thanks, and Gig 'em



TEXAS A&M UNIVERSITY
Engineering



Texas A&M Engineering
Experiment Station

Many thanks to my collaborators, mentors and funding agencies, and especially ERCOT for providing us with aggregated large flexible load dataset!