BUSINESS ANALYTICS PROJECT

STRATEGIC INSIGHTS INTO CARBON EMISSIONS AND BIDDING DYNAMICS IN THE AUSTRALIAN NATIONAL ELECTRICITY MARKET

DATA-DRIVEN ANALYSIS FOR RENEWABLE TRANSITION AND INVESTMENT STRATEGIES

Project Overview:

Our team analyzed the NEM’s renewable transition using Python, dissecting carbon emissions and bidding strategies. Through historical and current data, we provide actionable investment recommendations, supported by robust visualizations and analytics.

Navigating the Energy Transition in the NEM

Aim:

To deliver a comprehensive, data-driven analysis of the Australian National Electricity Market (NEM)'s carbon emission intensity, generator bidding behaviour, and so on, providing actionable insights and strategic recommendations for investment in renewable and fossil-fuel generation assets.

Key Tasks Addressed:

1. Analyzing NEM carbon emission trends and regional drivers.
2. Examining intra-daily emission patterns and consumer impacts.
3. Comparing 2025 bidding strategies across generation technologies.
4. Assessing bidding behavior changes (2019 vs. 2025).
5. Delivering investment recommendations for renewable and gas assets.

Meet the Team

Overview

1.Marzan Rahman
- Contribution: Task 1

2.Muntasir Md Nafis
- Contribution: Task 2

3.Battogtokh Myagmarjav
- Contribution: Task 2 & Trello

4.Ananya Pandey
- Contribution: Task 3

5.Nikita Farhin
- Contribution: Task 4

6.Hassan Mohammed
- Contribution: Task 5

Marzan Rahman

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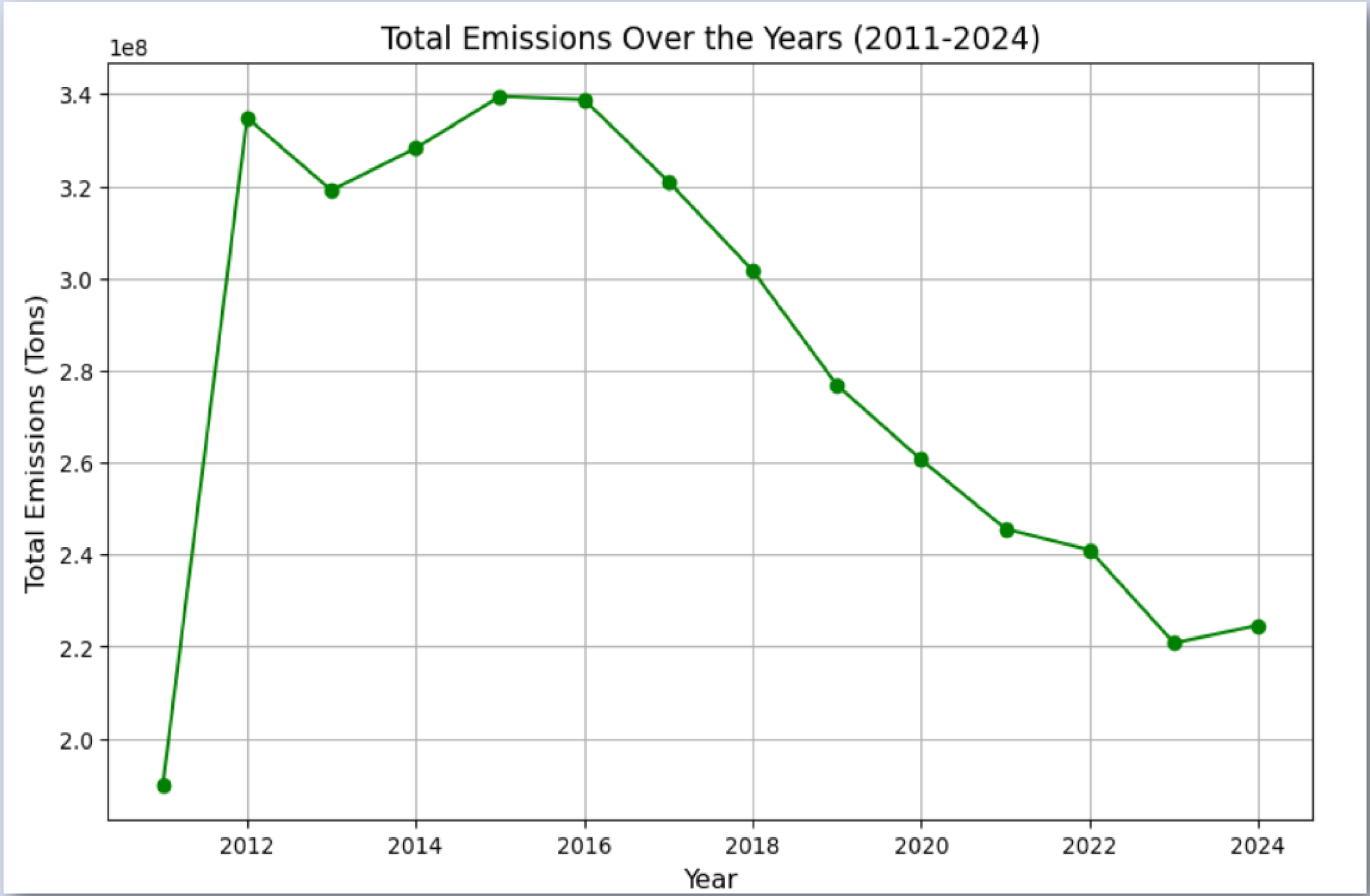
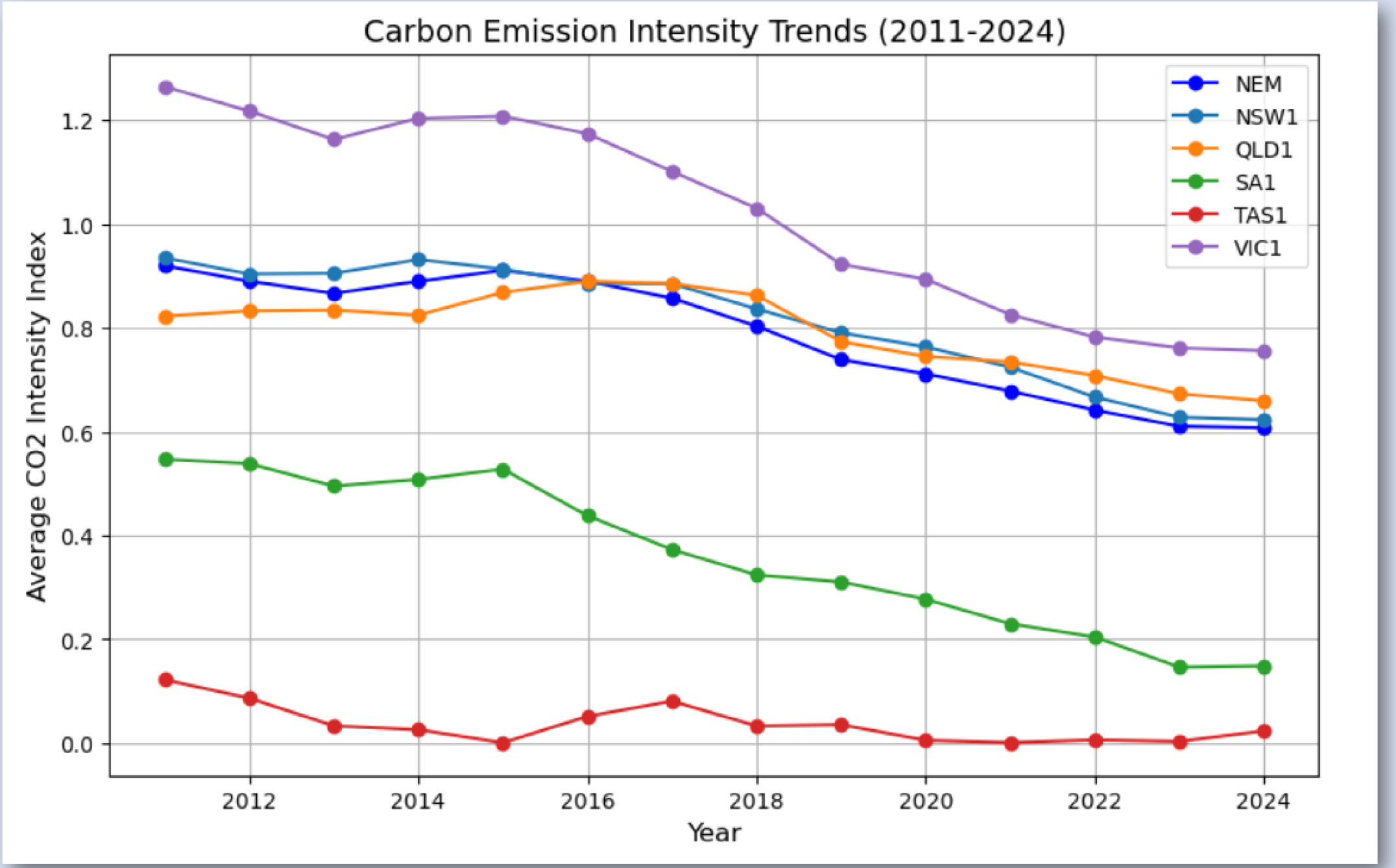
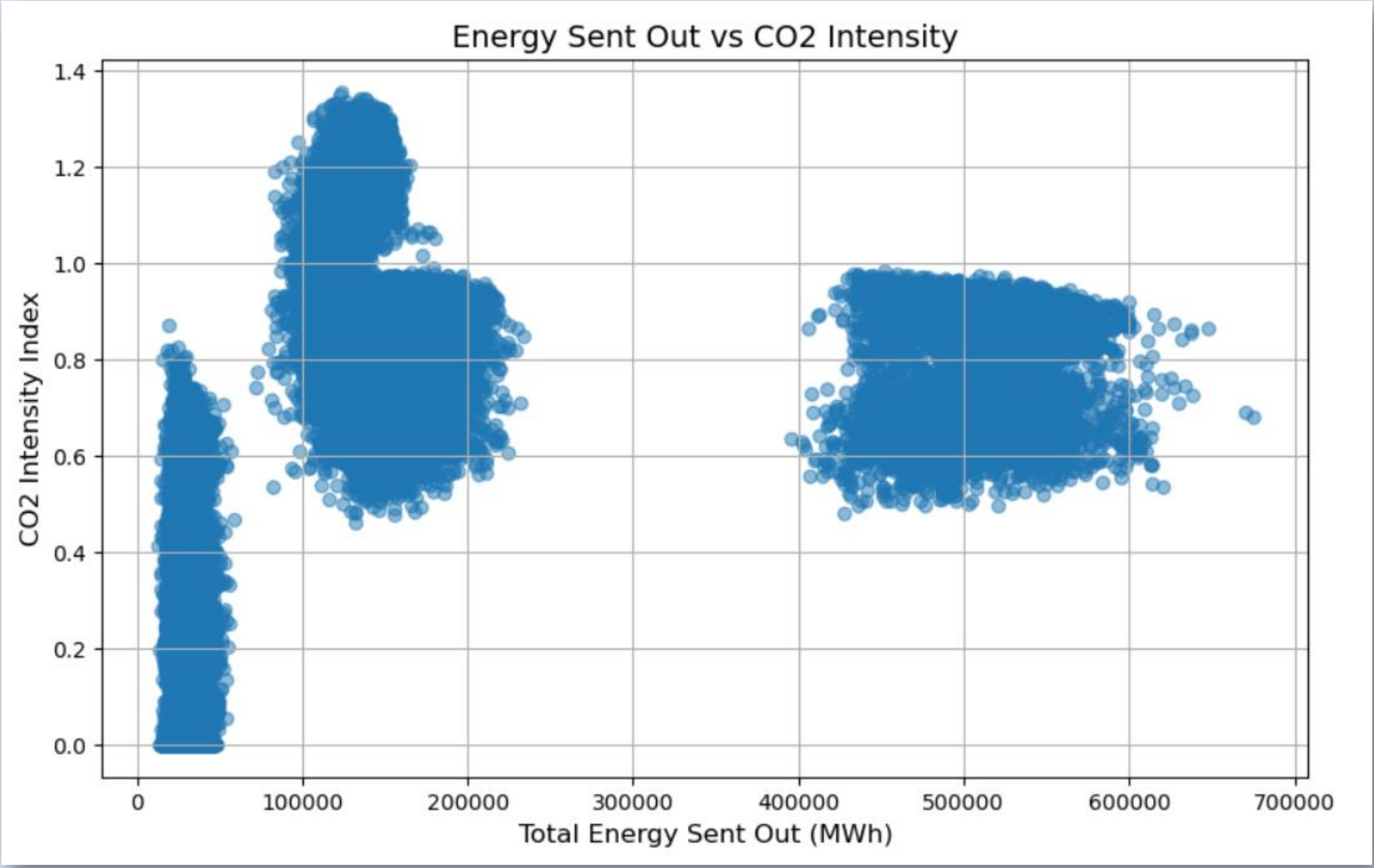
Emissions Over Time



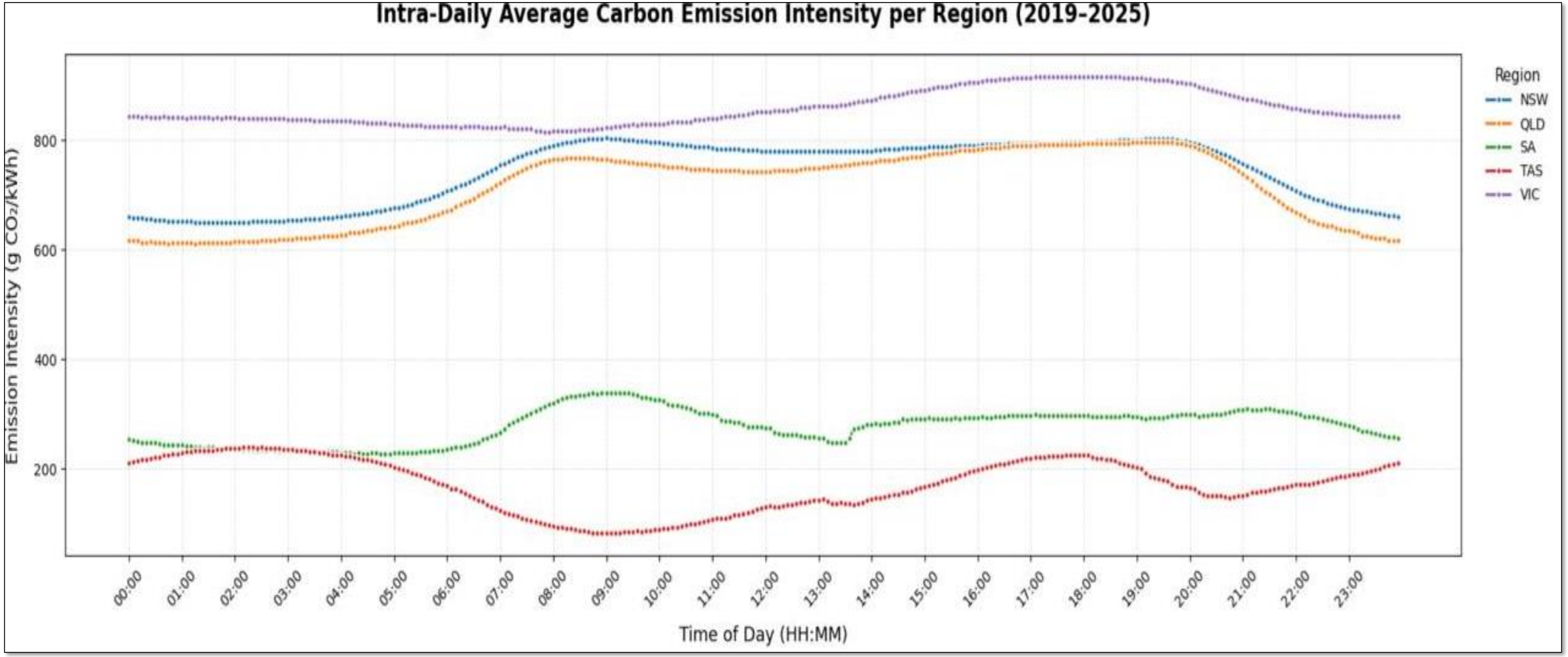
Emission Intensity Trend

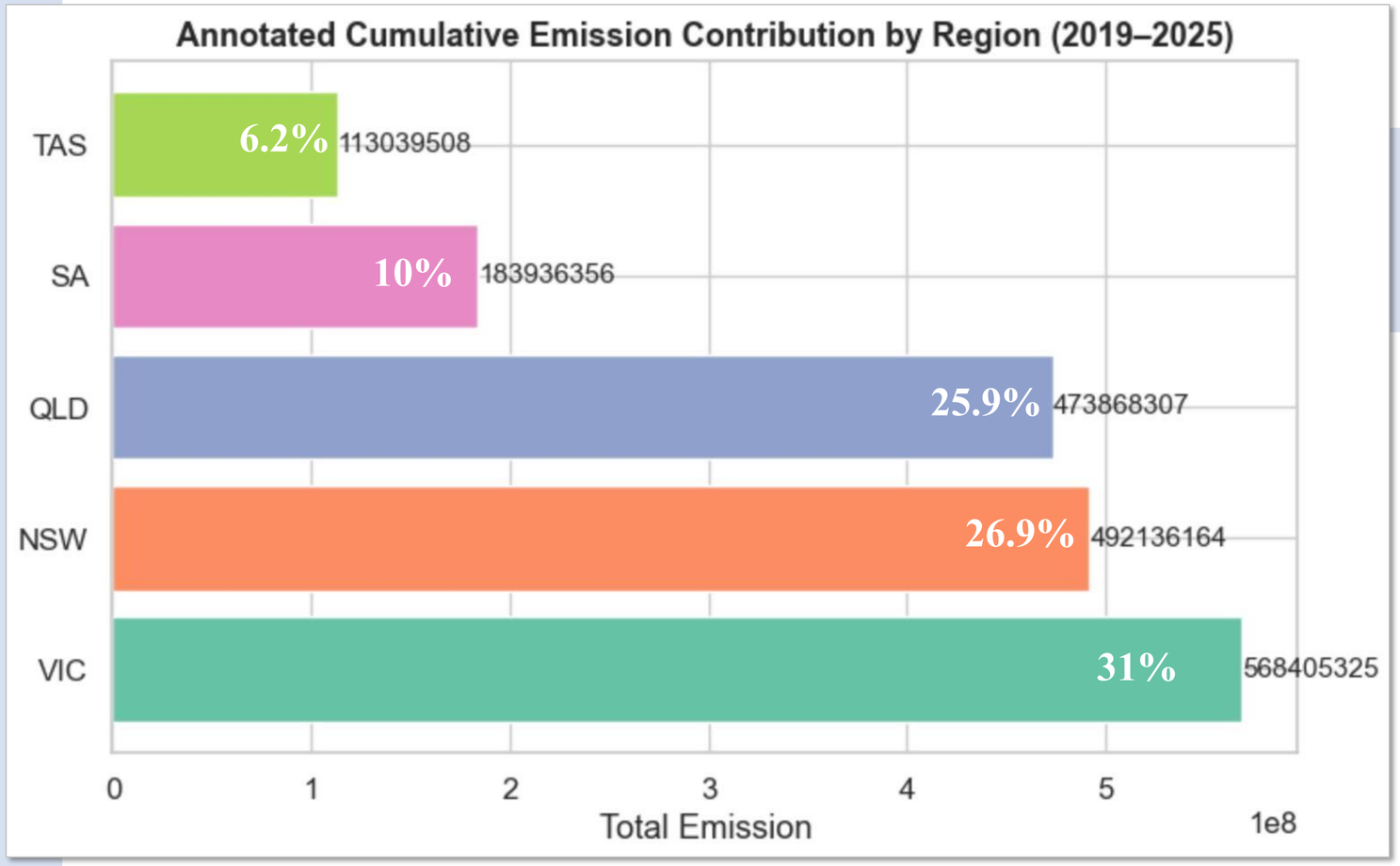


Energy Output vs. CO2 Intensity



Intra- Daily Emission Intensity

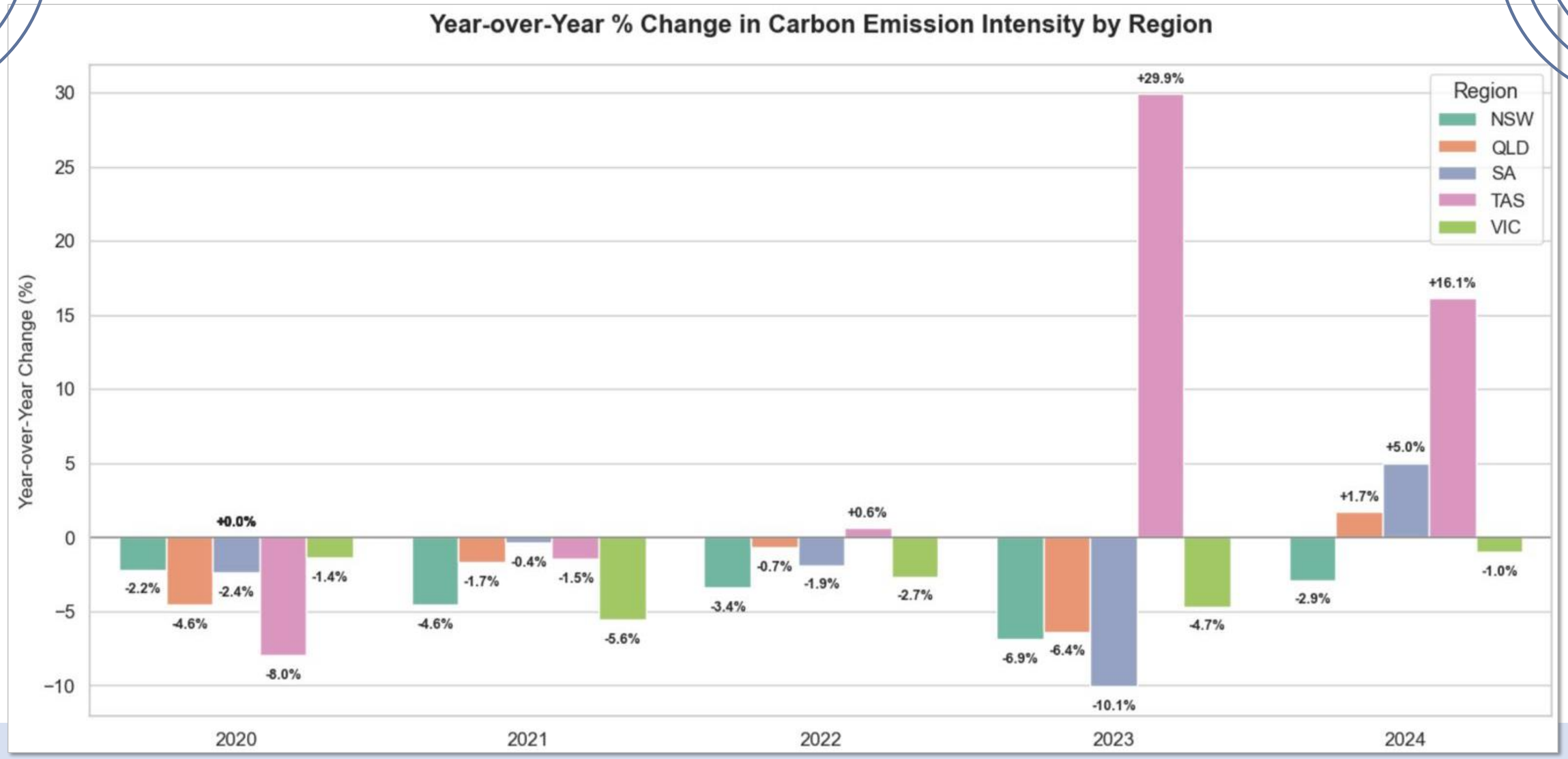




Cumulative Emission

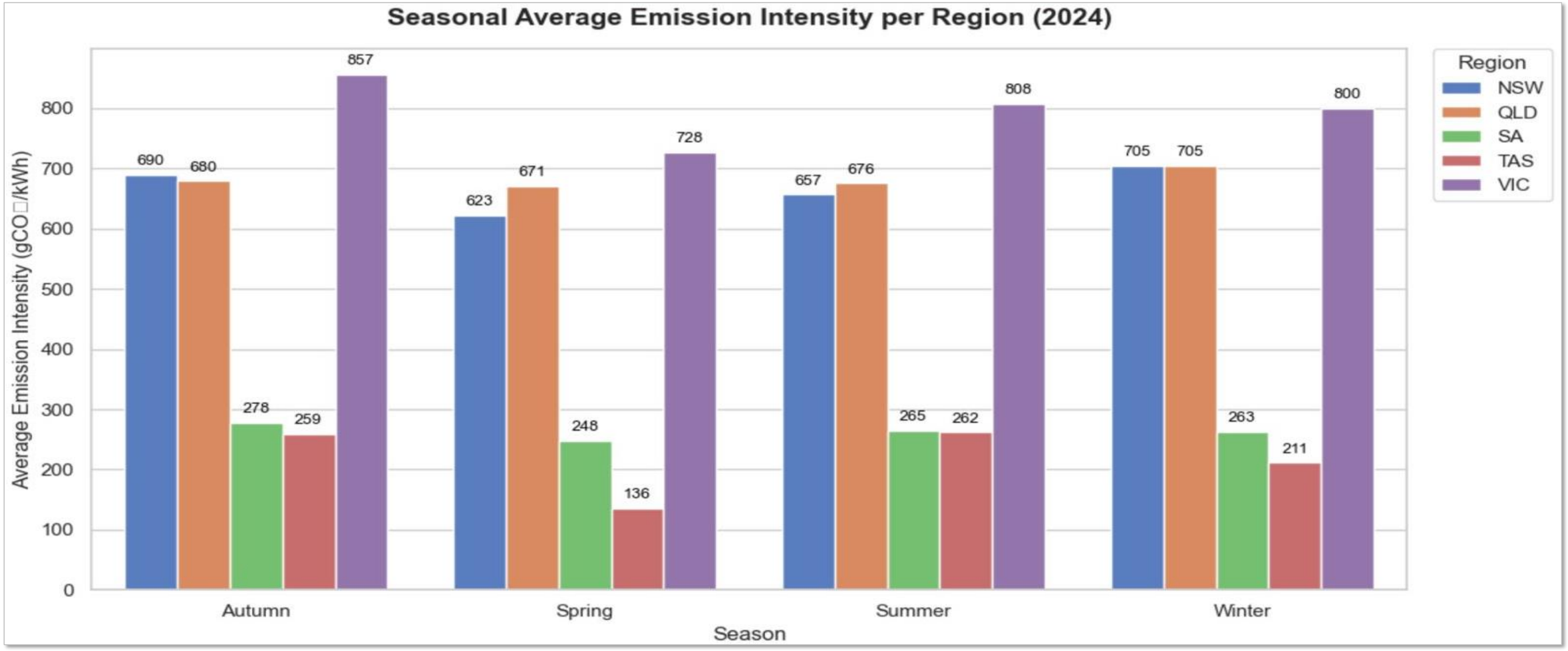
VIC leads with the highest cumulative emissions, followed closely by NSW and QLD, together accounting for over 83% of Australia's total emissions. In contrast, SA and TAS contribute significantly less, highlighting their more sustainable energy profiles.

Proposed Timeline

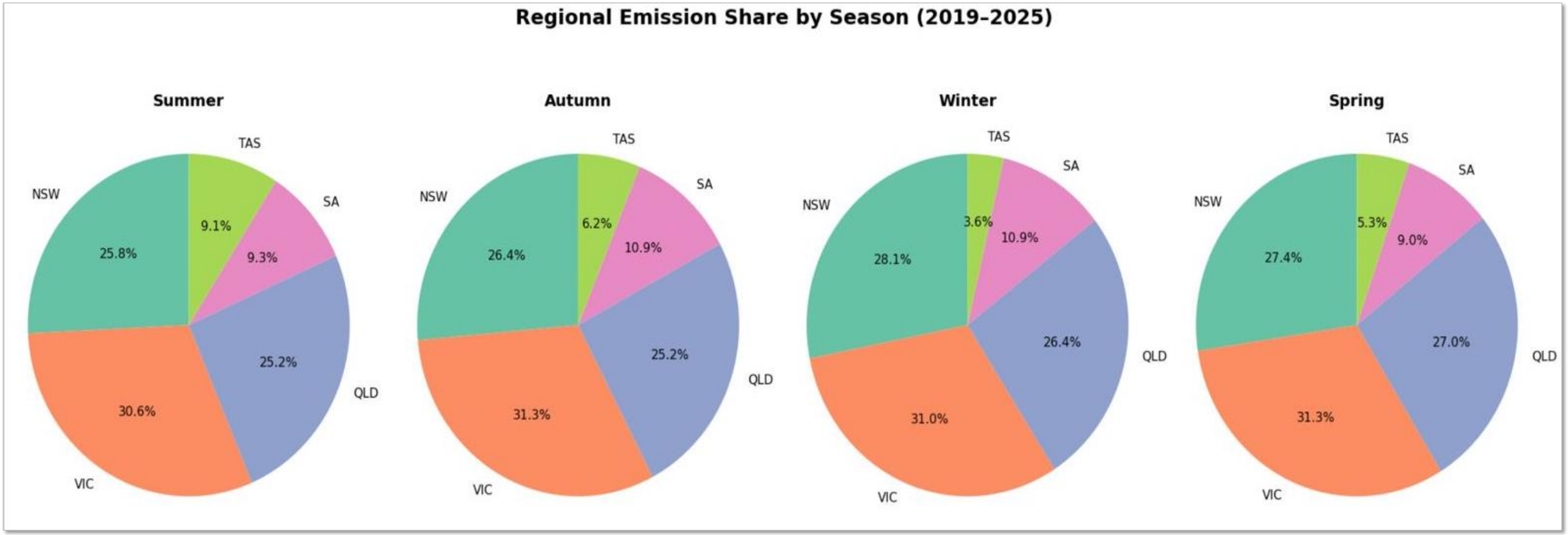


While most regions show gradual emission reductions, South Australia experienced sharp year-to-year spikes in 2023 and 2024, suggesting volatility in its energy mix or demand profile.

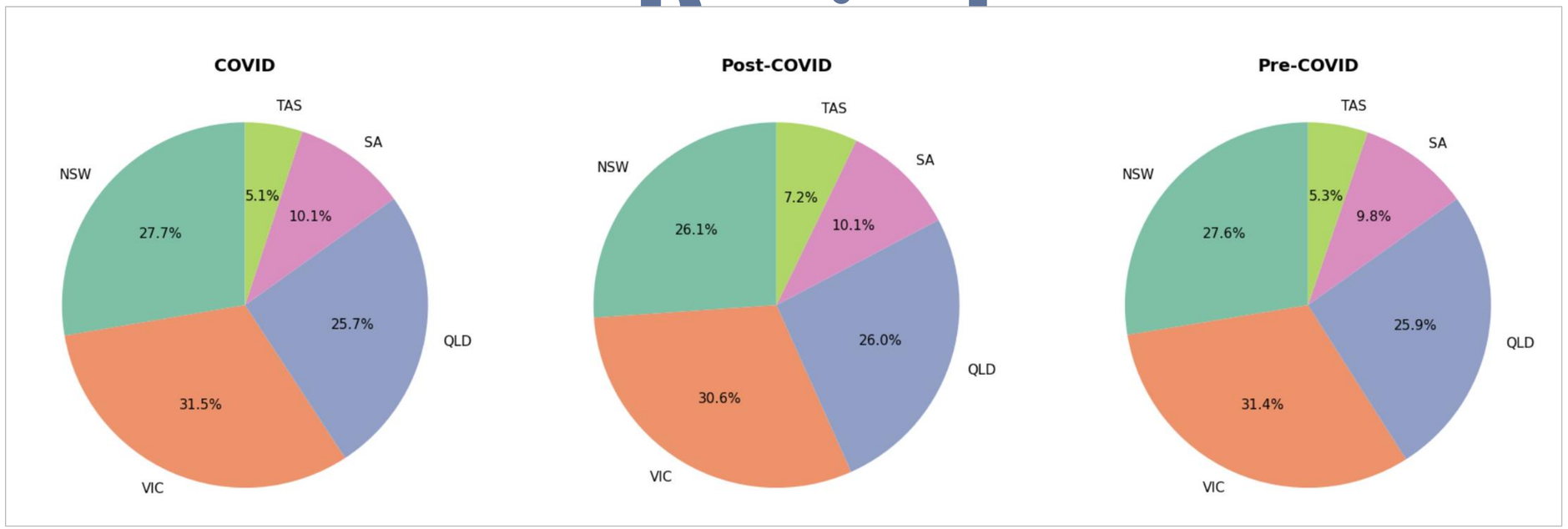
Season Trends by Region



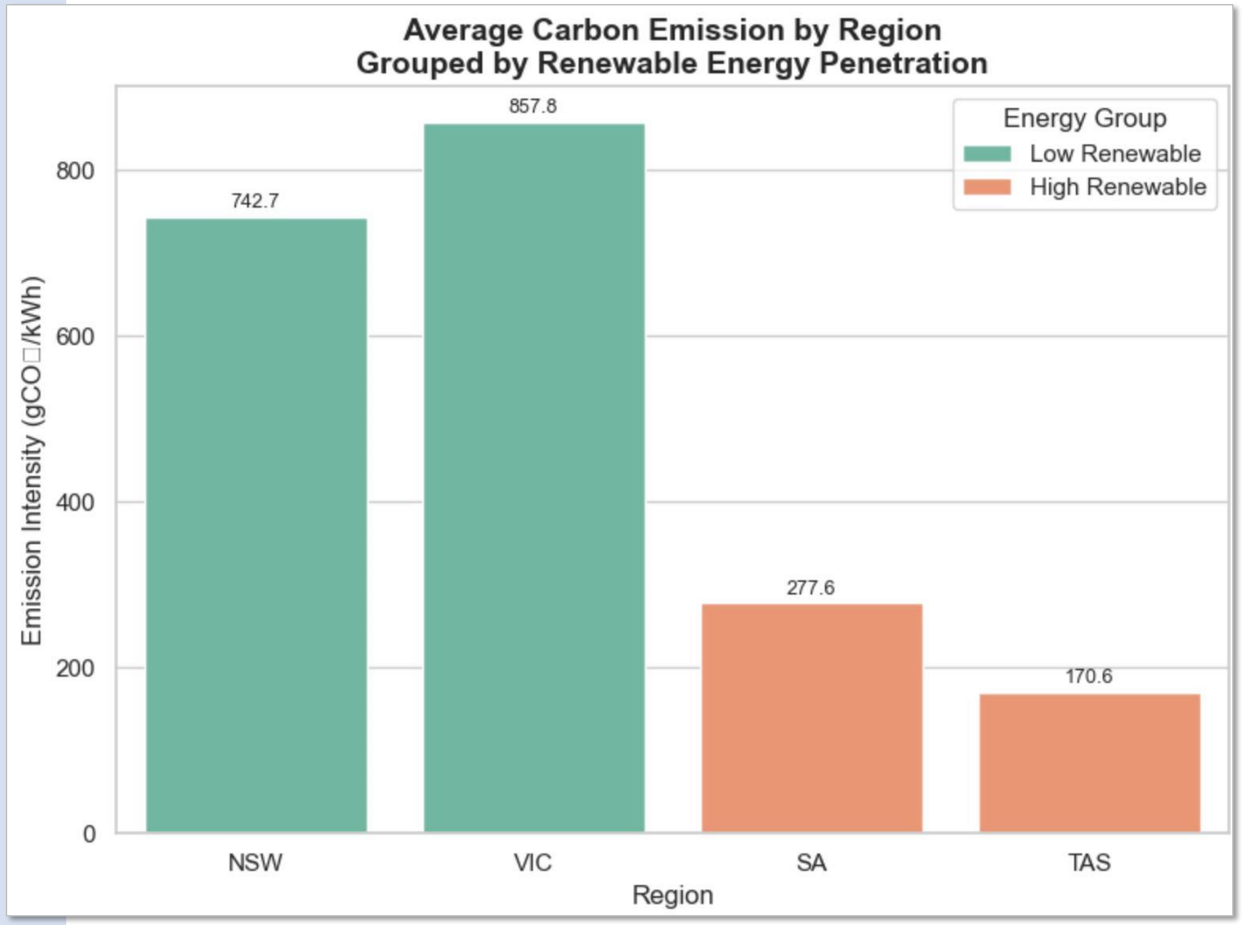
Season Trends by Region



Regional Emission by Period



Emission intensity dropped across all states during COVID, mainly due to reduced power demand. Victoria stayed the highest emitter, while Tasmania remained the cleanest state throughout.



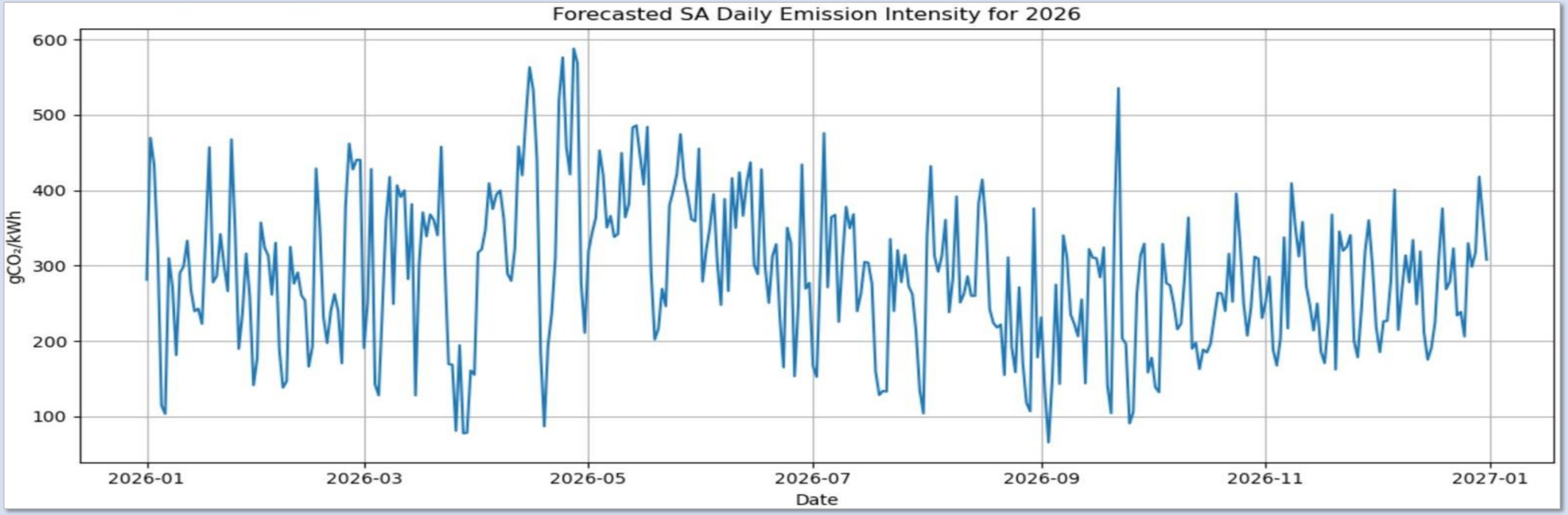
Analysis

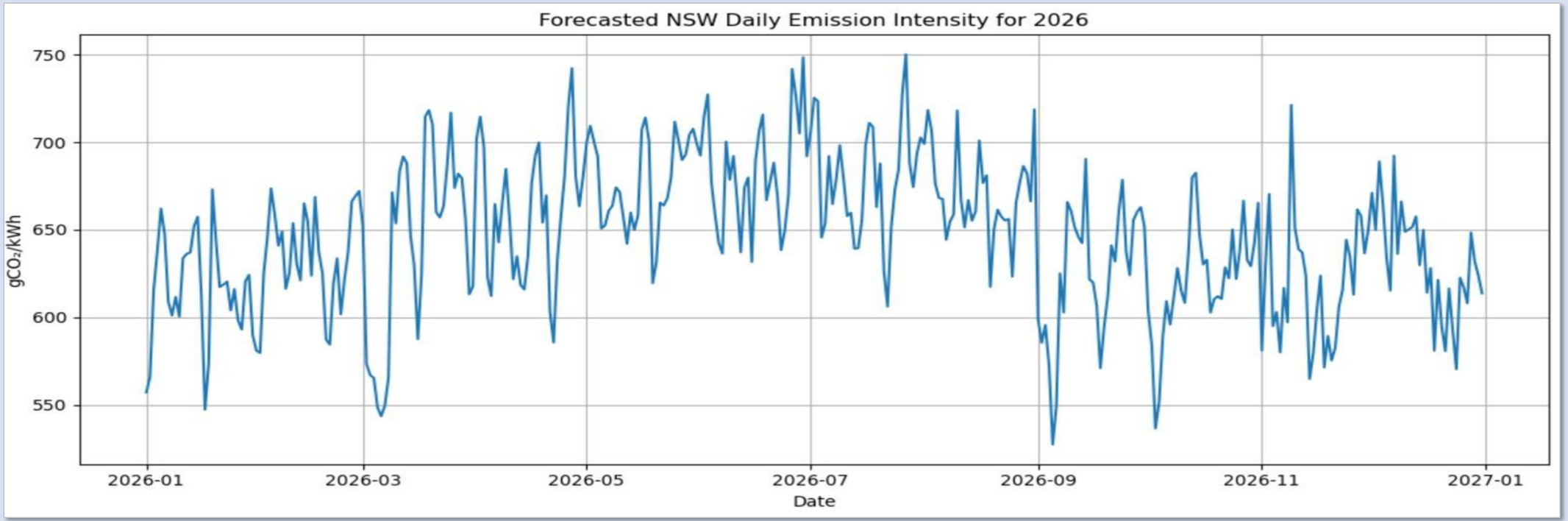
Regions with higher renewable energy use, like SA and TAS, show significantly lower and more stable emission intensities compared to VIC and NSW.

Emission Impacts of Renewables

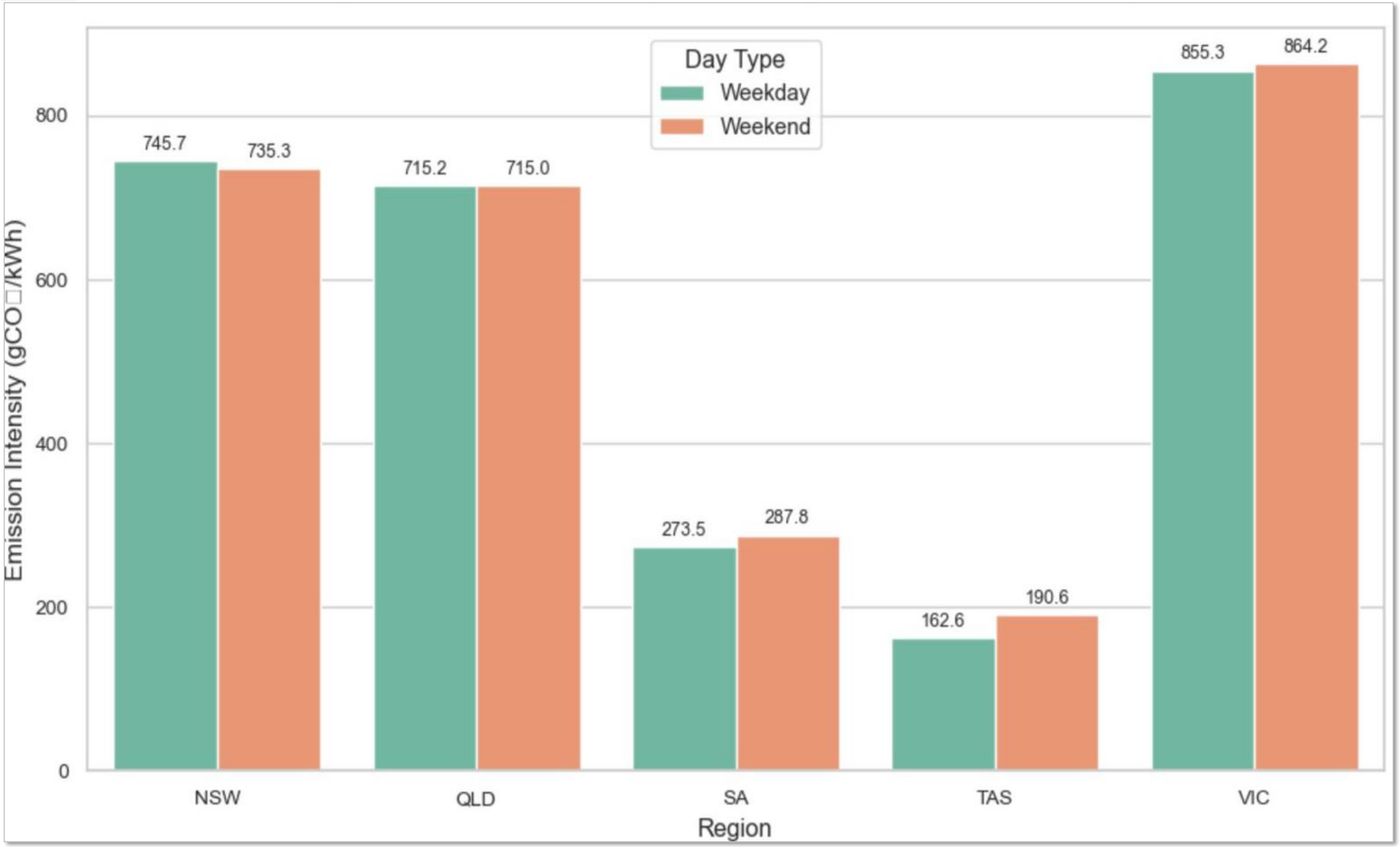
Write interpretation

Forecasted Daily Emission (2026) SA vs NSW

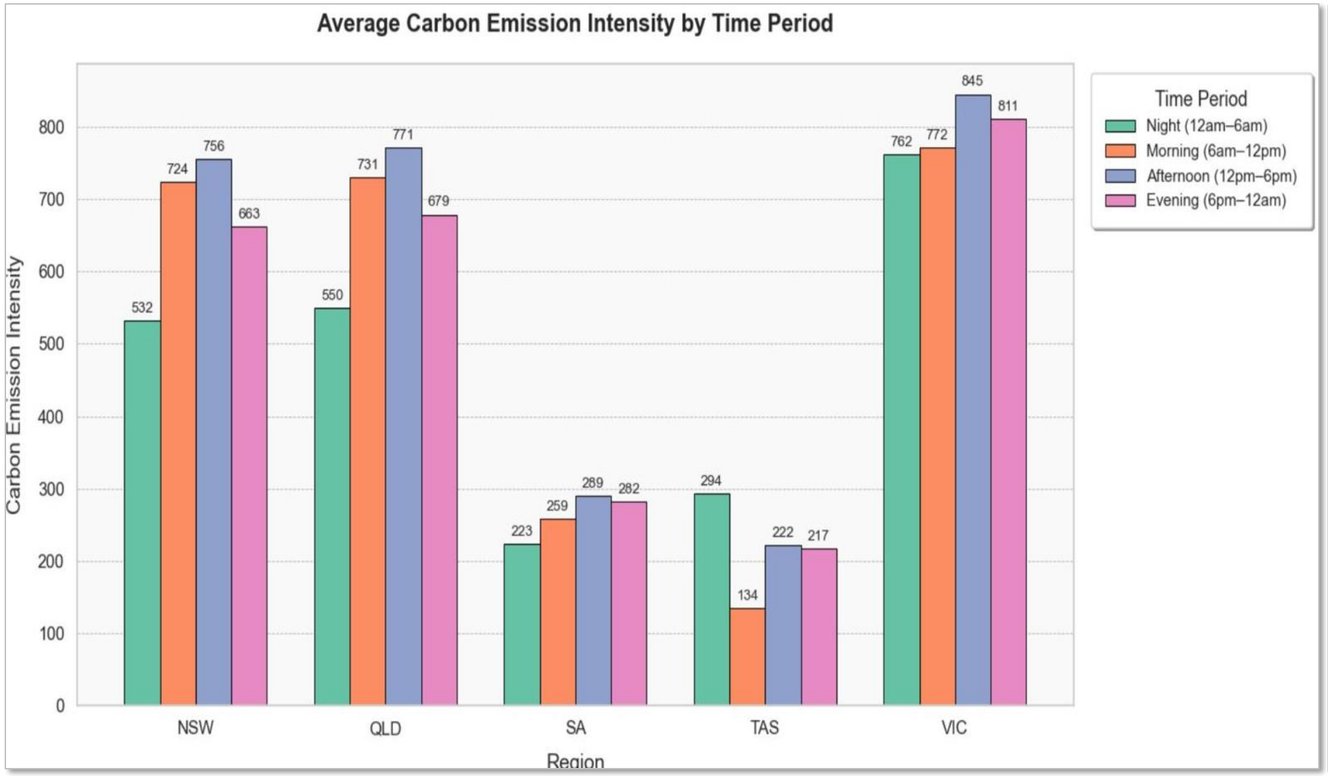


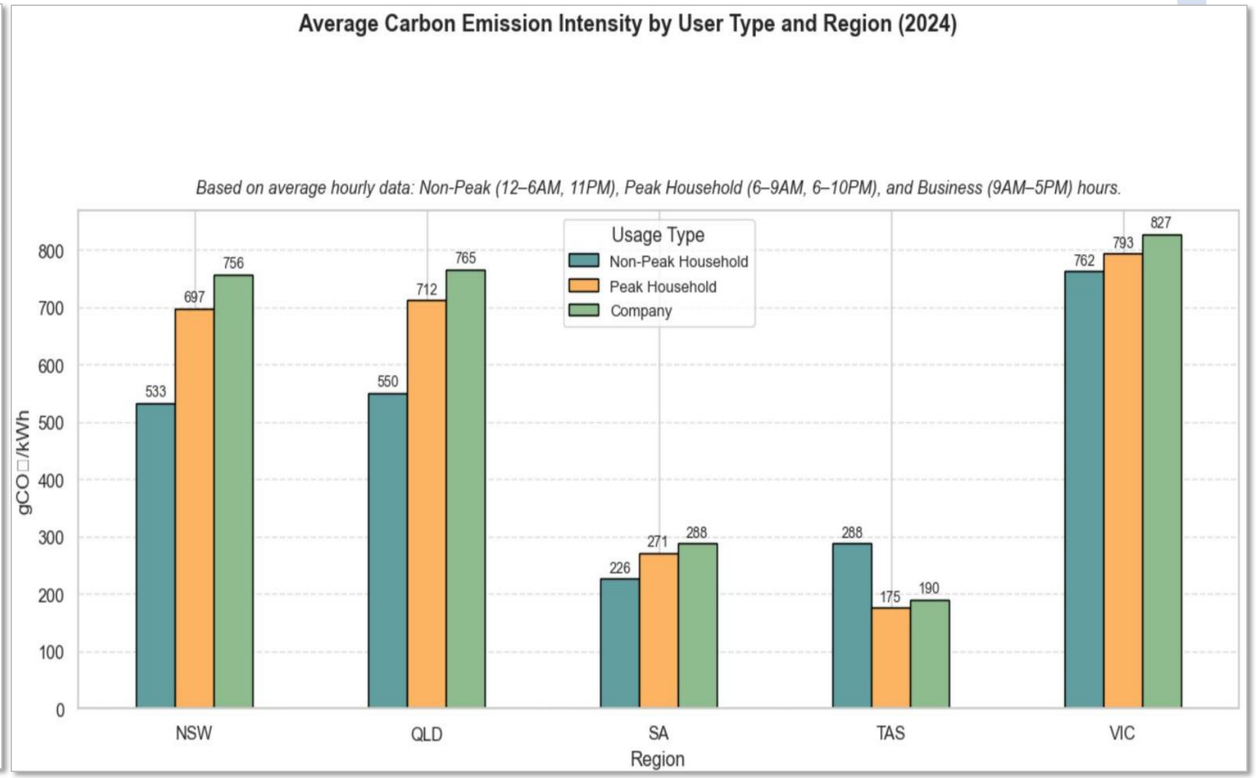


Average Emission Intensity – Weekdays vs Weekends



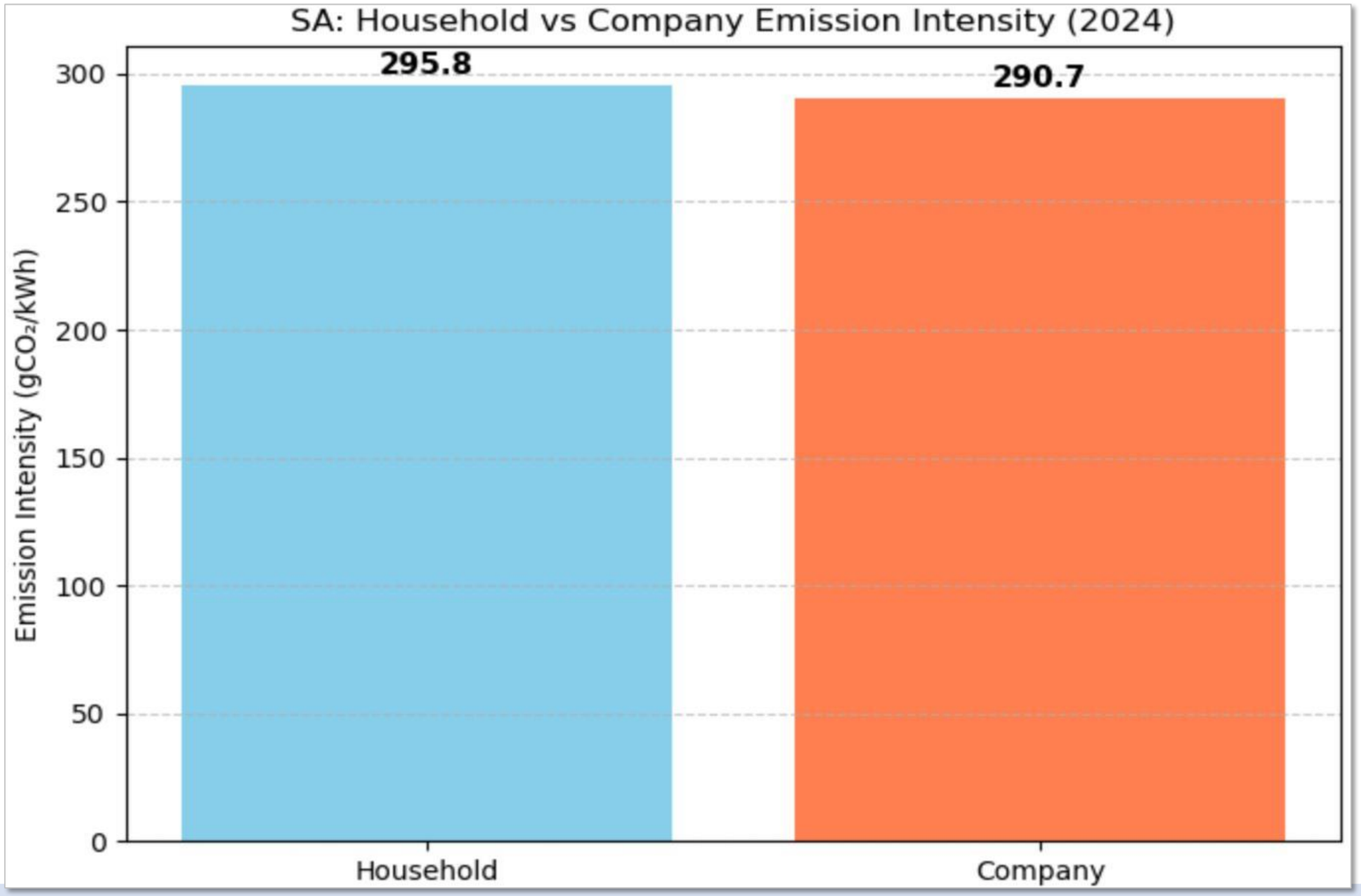
Daily Emission Intensity





Carbon intensity is highest during business hours across all regions, making household off-peak usage a more emission-efficient choice.

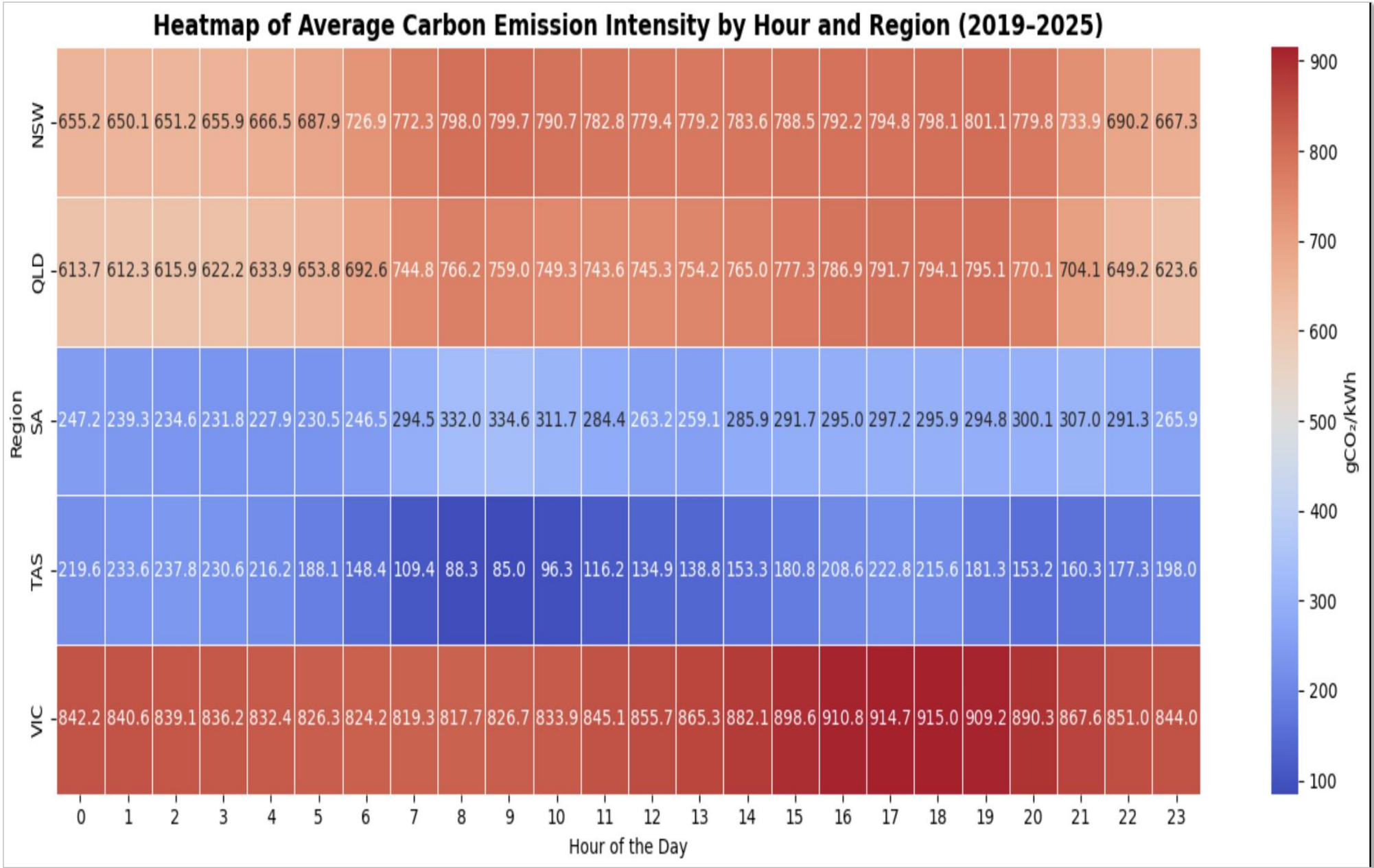
South Australia as a Green Energy Benchmark



In South Australia, companies emit slightly less carbon per unit of electricity than households, reflecting more efficient usage patterns

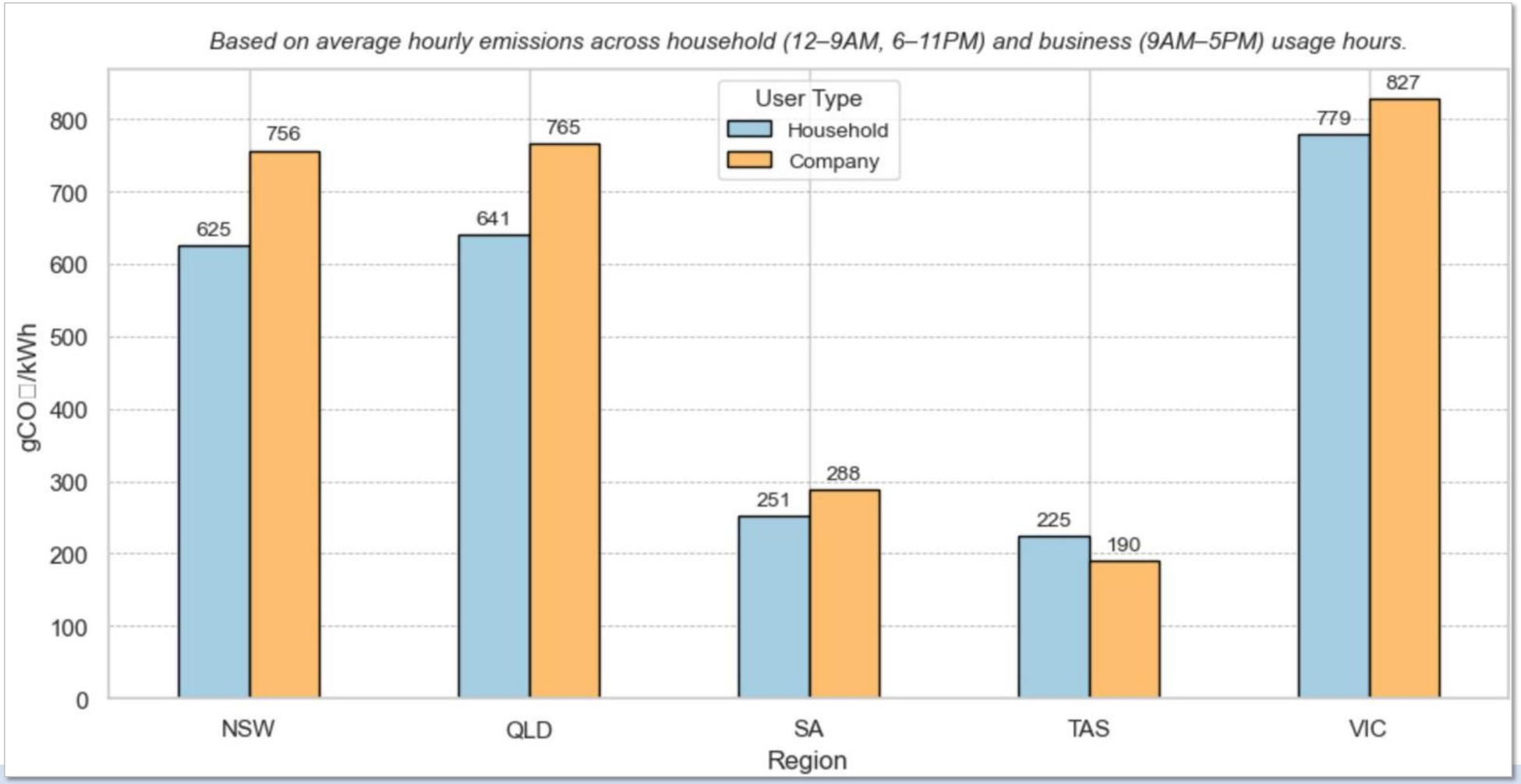
Hourly Emission Intensity

Carbon intensity is highest during business hours across all regions, making household off-peak usage a more emission-efficient choice.



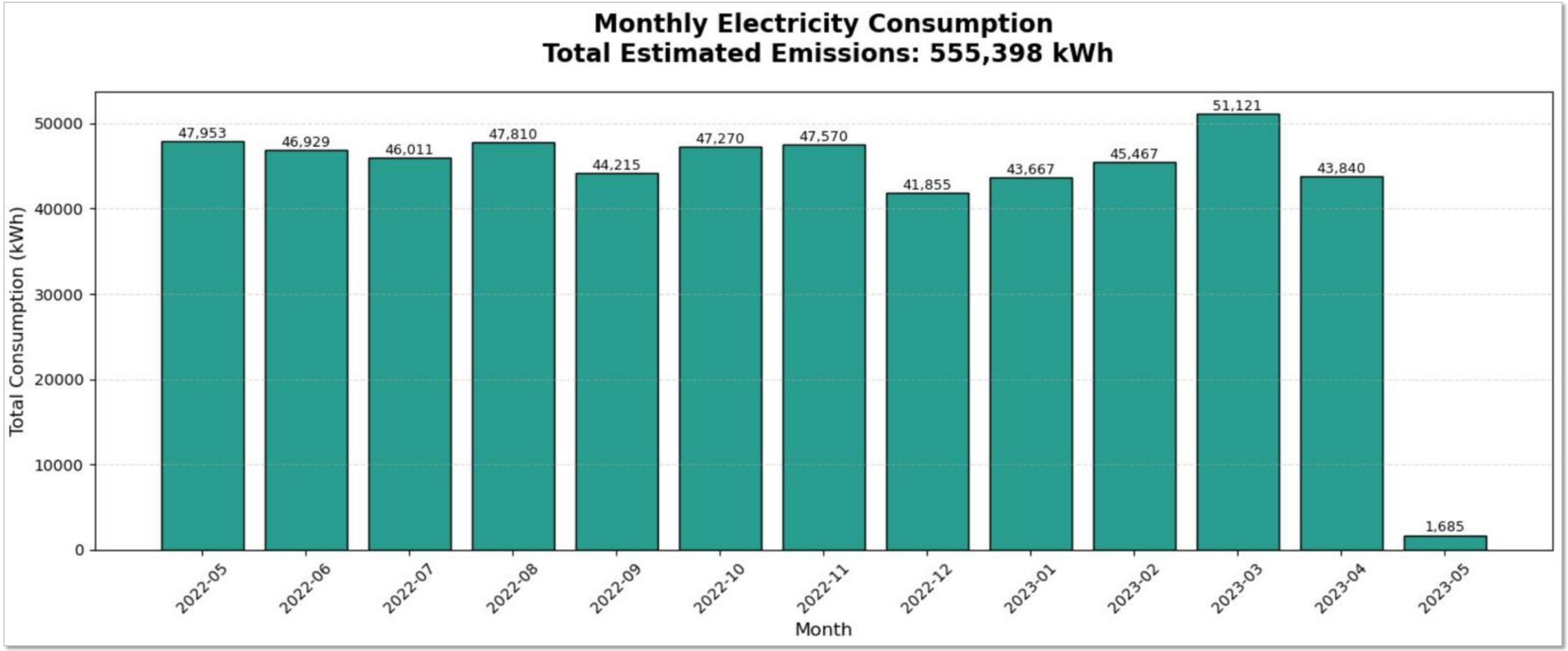
Average Carbon Emission Intensity – Household vs Company

(2024)

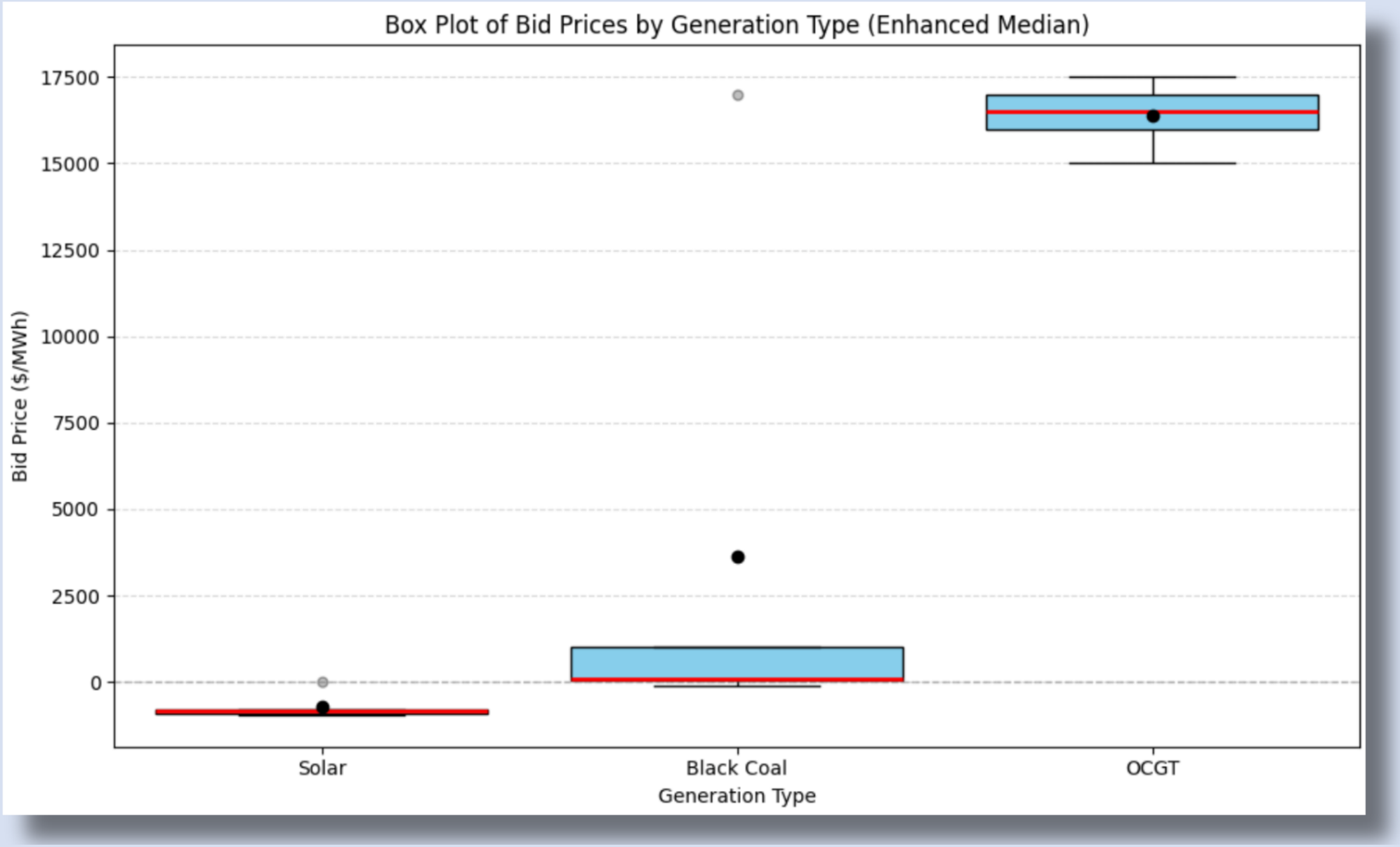


Company usage hours are more carbon-intensive than household hours in most regions, except TAS, where households emit more due to renewable variability

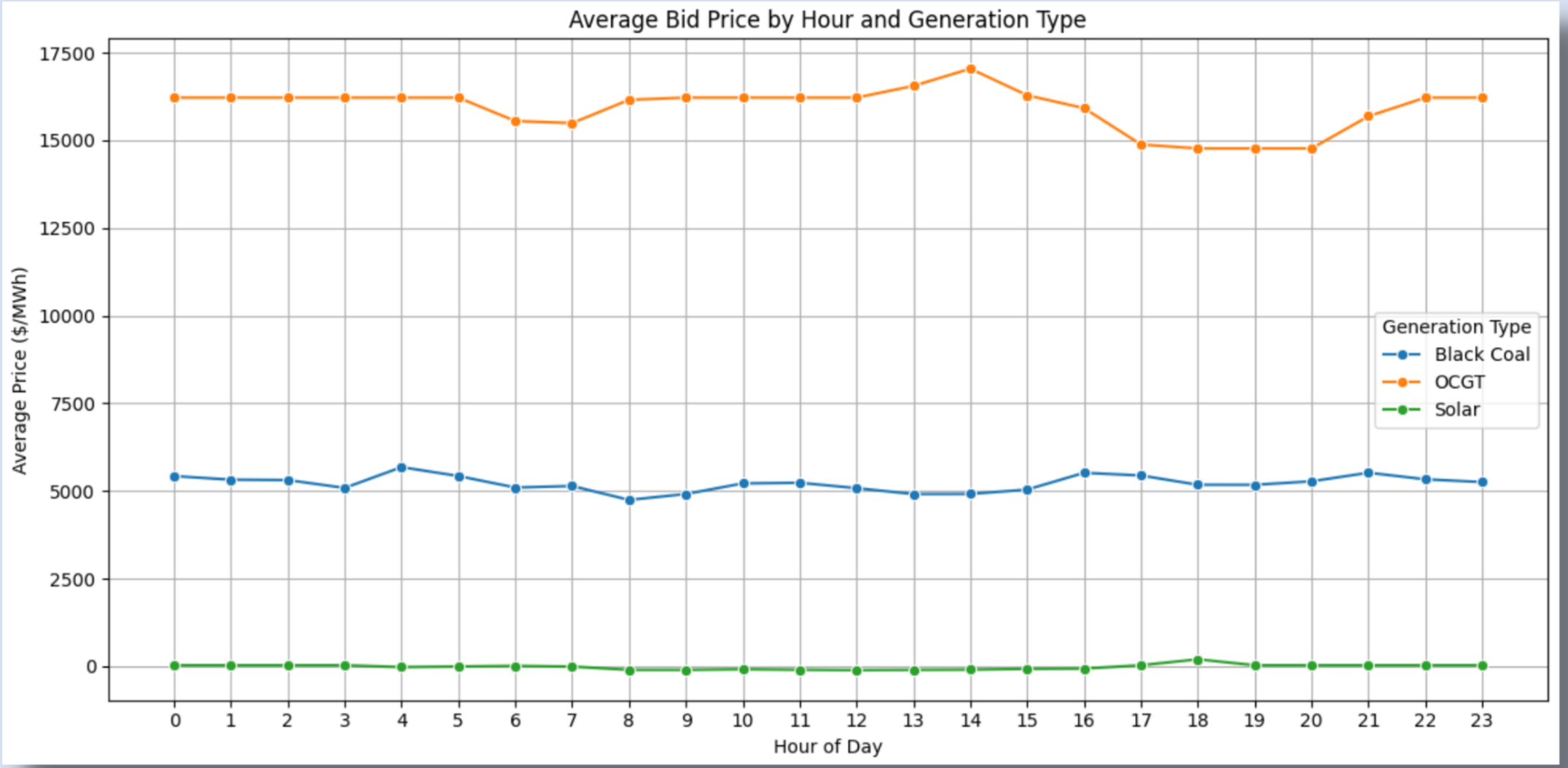
Company Electricity Consumption Trends - Monthly



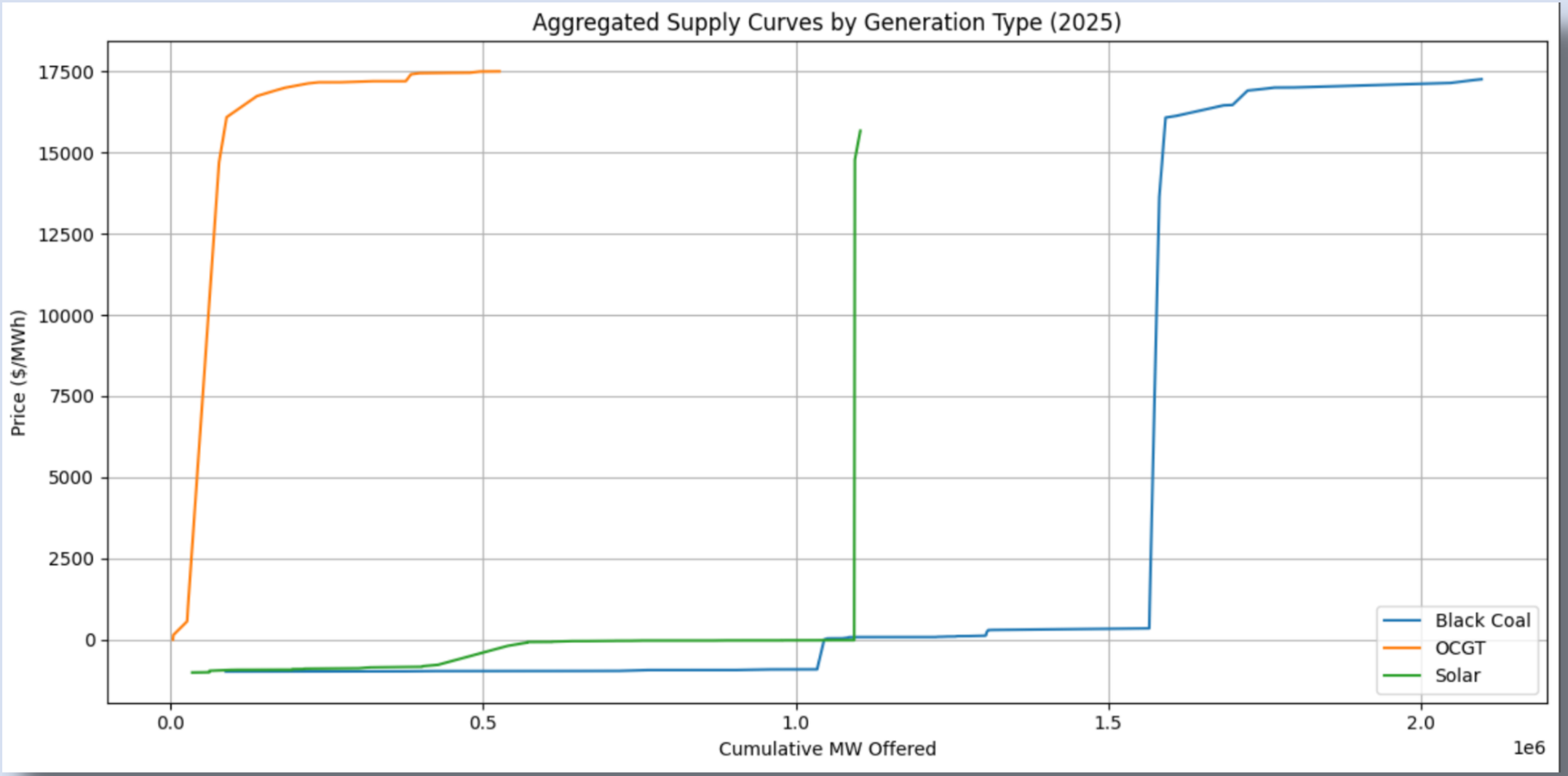
Compare Bidding Behaviour by Technology



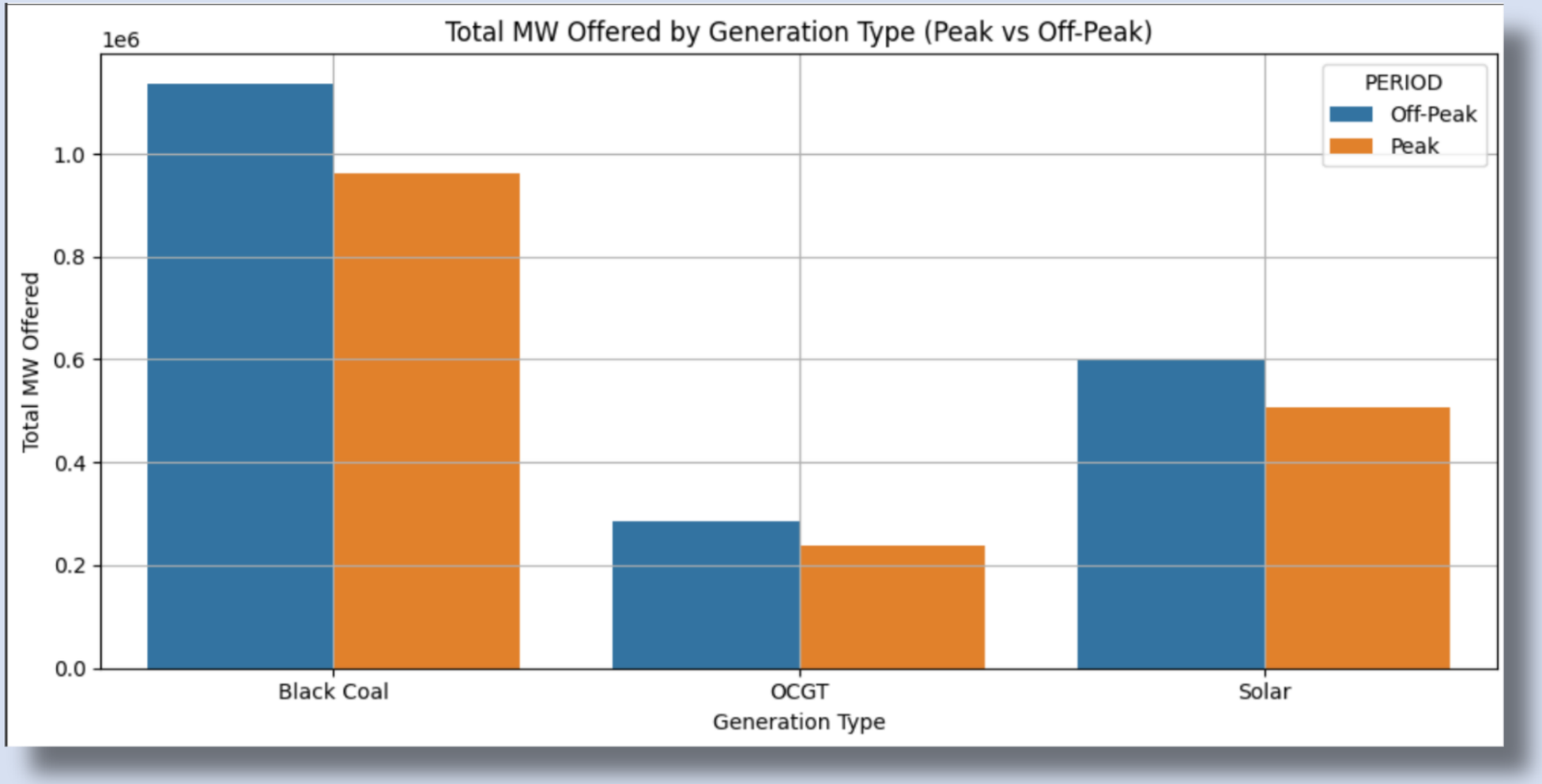
Evaluate if Bidding Changes by Time of Day



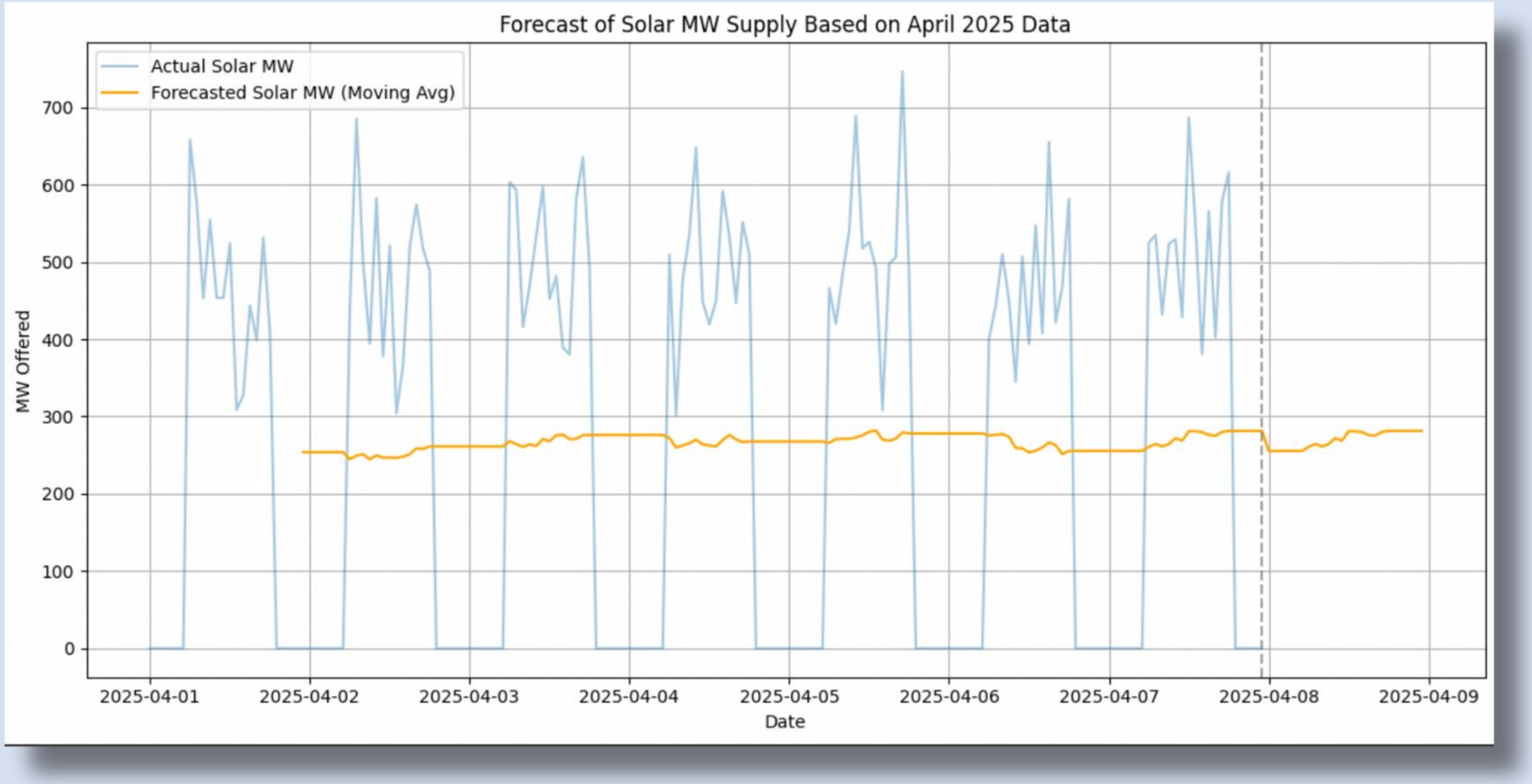
Look at Aggregated Supply Curves (April 2025)



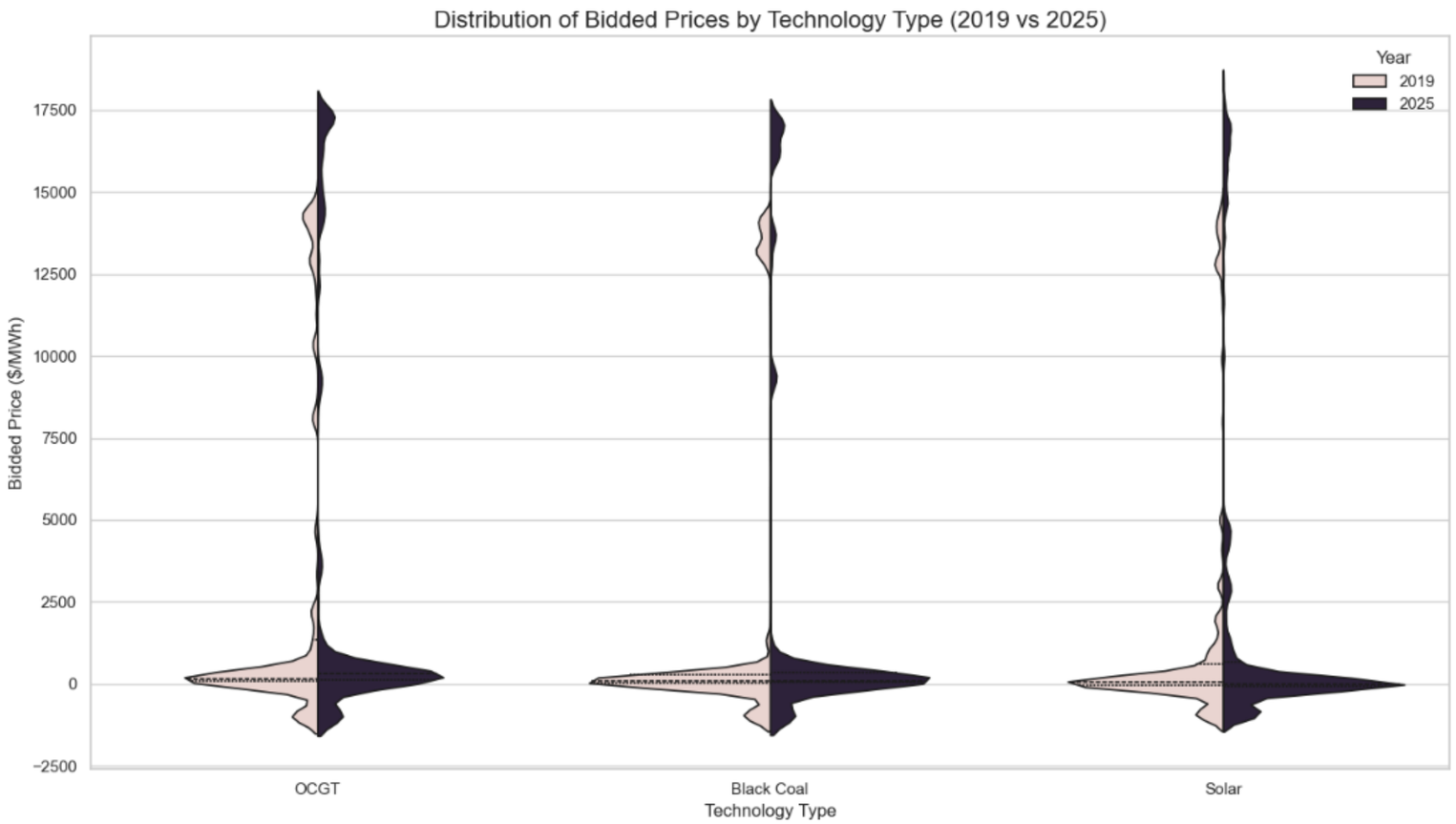
MW Supply by Generator Type: Peak vs Off-Peak Comparison



Forecast of Solar MW Supply Based on April 2025 Data



Distribution of Bidded Prices by Technology Type (2019 vs 2025) - Violin Plot



Key Observations:

- OCGT & Black Coal: Both years show dual-regime bidding: high density at low prices (near zero) and a substantial tail extending to over $15,000/MWh.
- OCGT (2025): Upper tail appears slightly wider/denser at higher prices than 2019.
- Solar (2025): Shows a more pronounced tail extending to higher prices, unlike 2019's tighter low-price concentration.

Key Interpretations:

- Thermal Dual Role: OCGT & Black Coal use low bids for energy demand and high bids for scarcity/flexibility.
- Reduced Extreme Thermal Spikes: 2025 sees a reduction in density of extreme upper tail bids (>$10,000/MWh), indicating fewer extreme scarcity events or strategic shift.
- Solar's Evolving Value Capture: Growing density of Solar bids at higher prices in 2025 suggests hybrid operations (e.g., with battery) or strategic bidding for greater value beyond marginal energy dispatch.

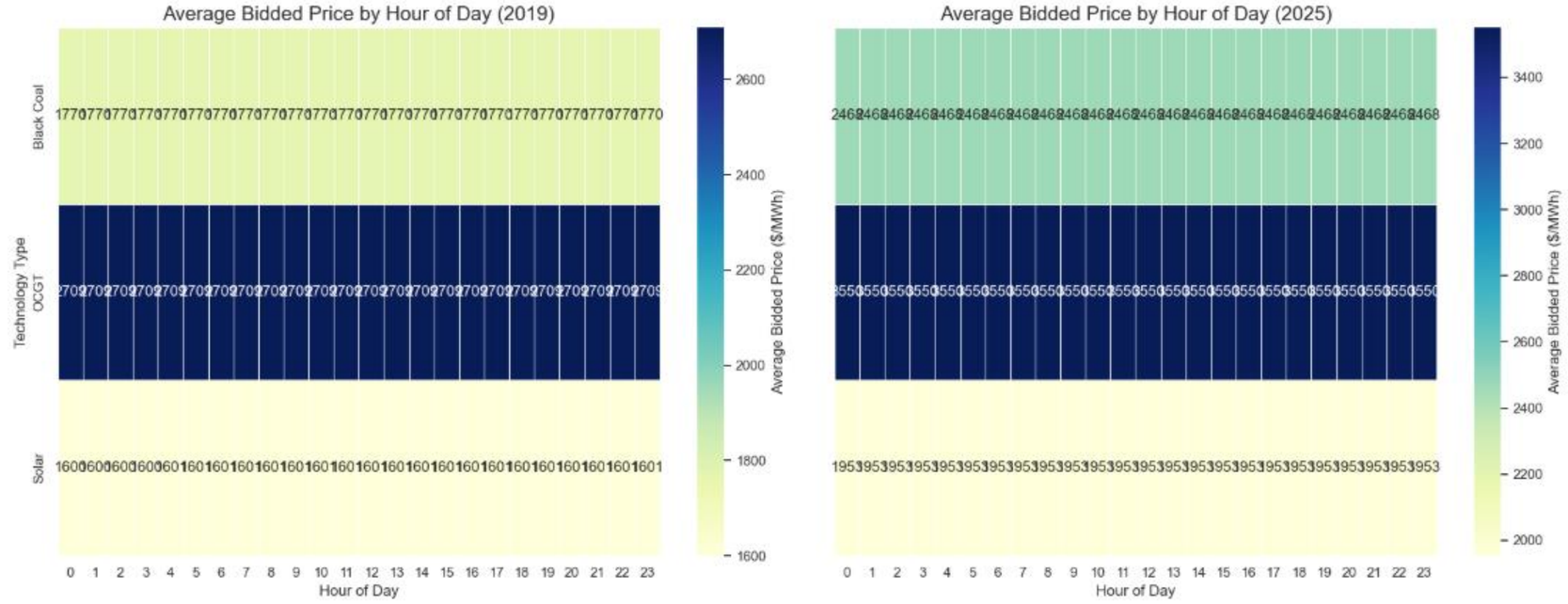
Average Bidded Price by Hour of Day (2019 vs 2025)

Key Observations

- Black Coal: 2019: ~1,770 $/MWh across all hours; 2025: rises to ~2,400 $/MWh.
- OCGT: 2019: ~2,700 $/MWh; 2025: increases to ~3,050 $/MWh.
- Solar: 2019: ~160 $/MWh (daytime); 2025: ~195 $/MWh (daytime), absent at night.

Key Interpretation

- Thermal Generators: Higher bids reflect rising costs or strategic pricing for flexibility/reliability as renewables grow.
- Solar: Low bids persist, with slight increases possibly due to opportunity costs or hybrid operations.



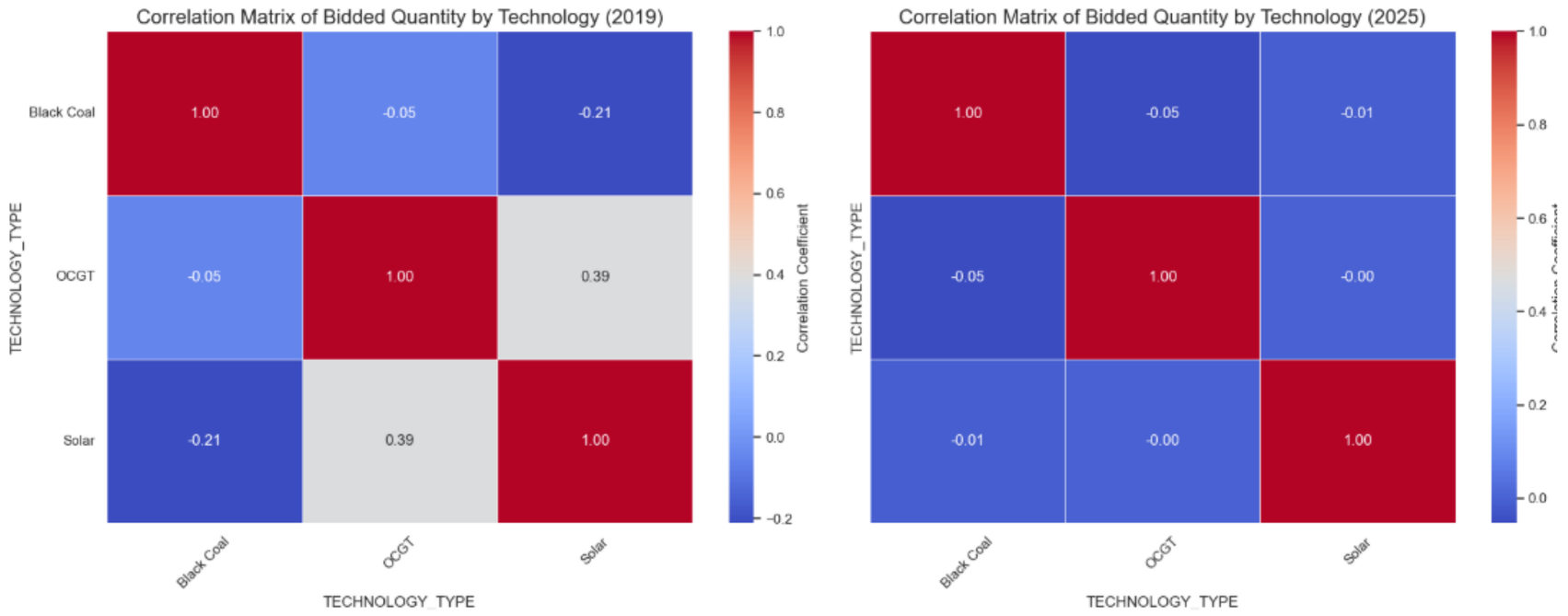
Correlation Matrix of Bidded Quantity by Technology (2019 vs 2025)

Key Observations

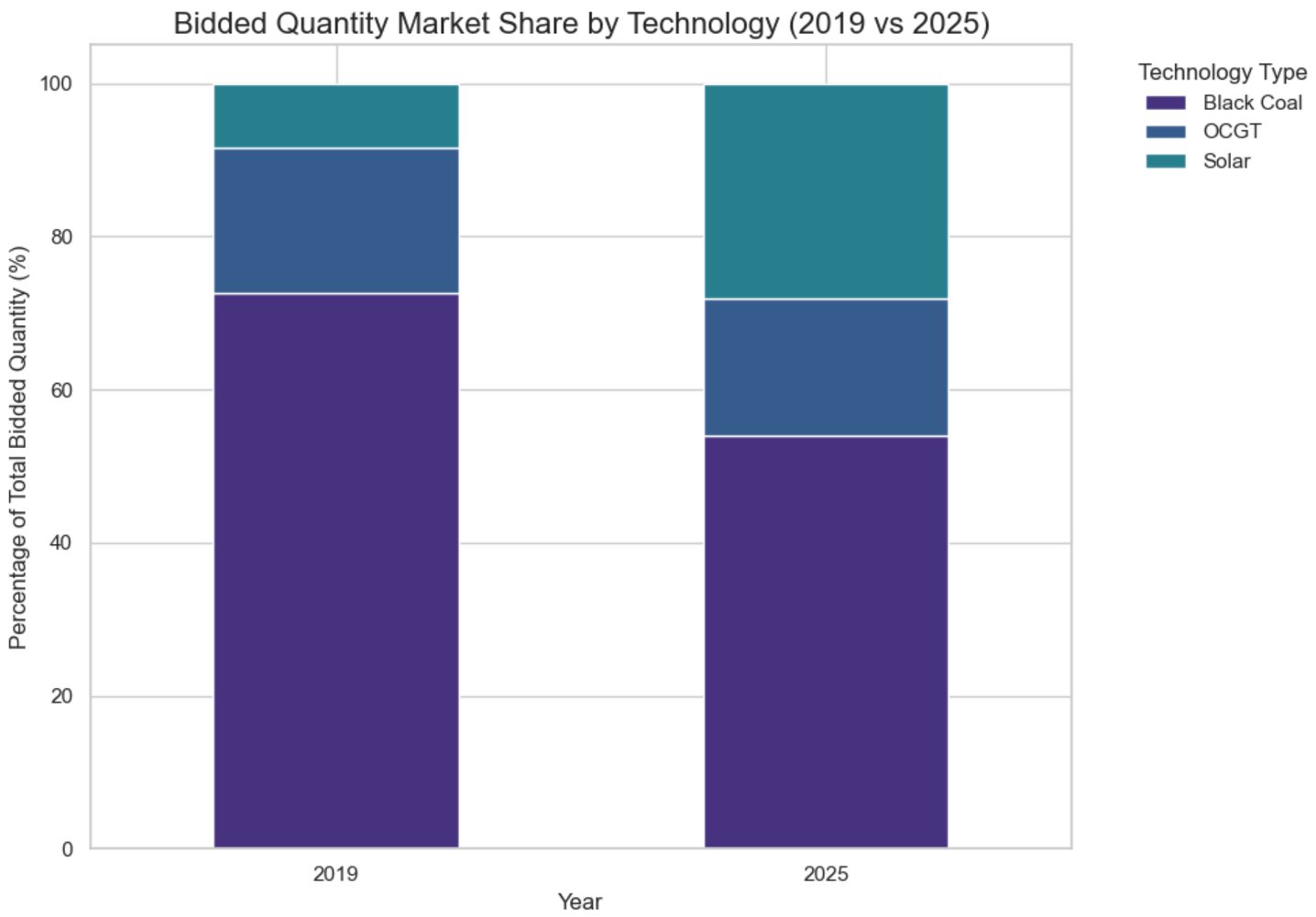
- 2019: Black Coal vs. OCGT: -0.05; Black Coal vs. Solar: -0.21; OCGT vs. Solar: 0.39.
- 2025: Black Coal vs. OCGT: -0.05; Black Coal vs. Solar: -0.01; OCGT vs. Solar: -0.00.
- Market specialization grows as solar dominates energy volume, thermal focuses on flexibility.

Key Interpretation

- Solar Decoupling: Solar bids less correlated with thermal in 2025, indicating independent growth or distinct market roles.
- Thermal Stability: Black Coal and OCGT maintain weak correlation, reflecting separate baseload/peaking roles.



Bidded Quantity Market Share by Technology (2019 vs 2025)



Key Observations:

- 2019: Black Coal dominates (~70%), OCGT (~20%), Solar (~10%).
- 2025: Black Coal significantly decreases (~50-55%), OCGT stable/slightly decreases (~15%), Solar dramatically increases (~30-35%).

Key Interpretations:

- Direct evidence of the energy transition: Solar's substantial market share increase directly at the expense of Black Coal.
- Reduction in Black Coal's share indicates a move away from its role as the primary, constant baseload energy source.
- Stable OCGT share highlights its continued importance for flexibility and rapid response, shifting its role from energy volume to capacity/firming.

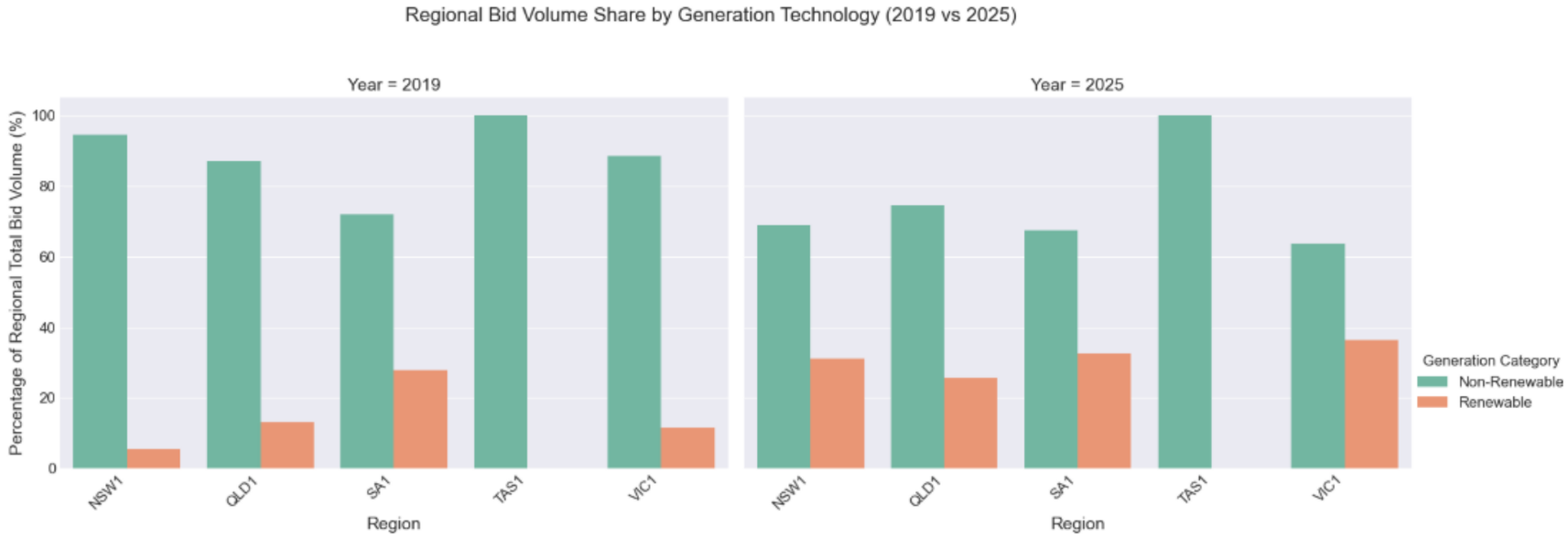
Regional Bid Volume Share by Generation Technology (2019 vs 2025)

Key Observations

- 2019: "Non-Renewable" (OCGT/Black Coal) dominates (85-99%) across all regions. Solar contribution is minimal.
- 2025:SA1 & VIC1: Most noticeable shifts, with Solar increasing to ~30-40% share.
- NSW1 & QLD1: Show dramatic shifts, with Solar reaching ~25-35%.
- TAS1: Remains dominated (>95%) by "Non-Renewable" (OCGT/Black Coal), with marginal Solar growth.

Key Interpretation

- Renewable Growth: SA1 & VIC1 lead renewable integration; NSW1 & QLD1 show significant solar increases.
- TAS1's Thermal Consistency: Consistent OCGT/Black Coal dominance explains its stable low-cost bid stack.



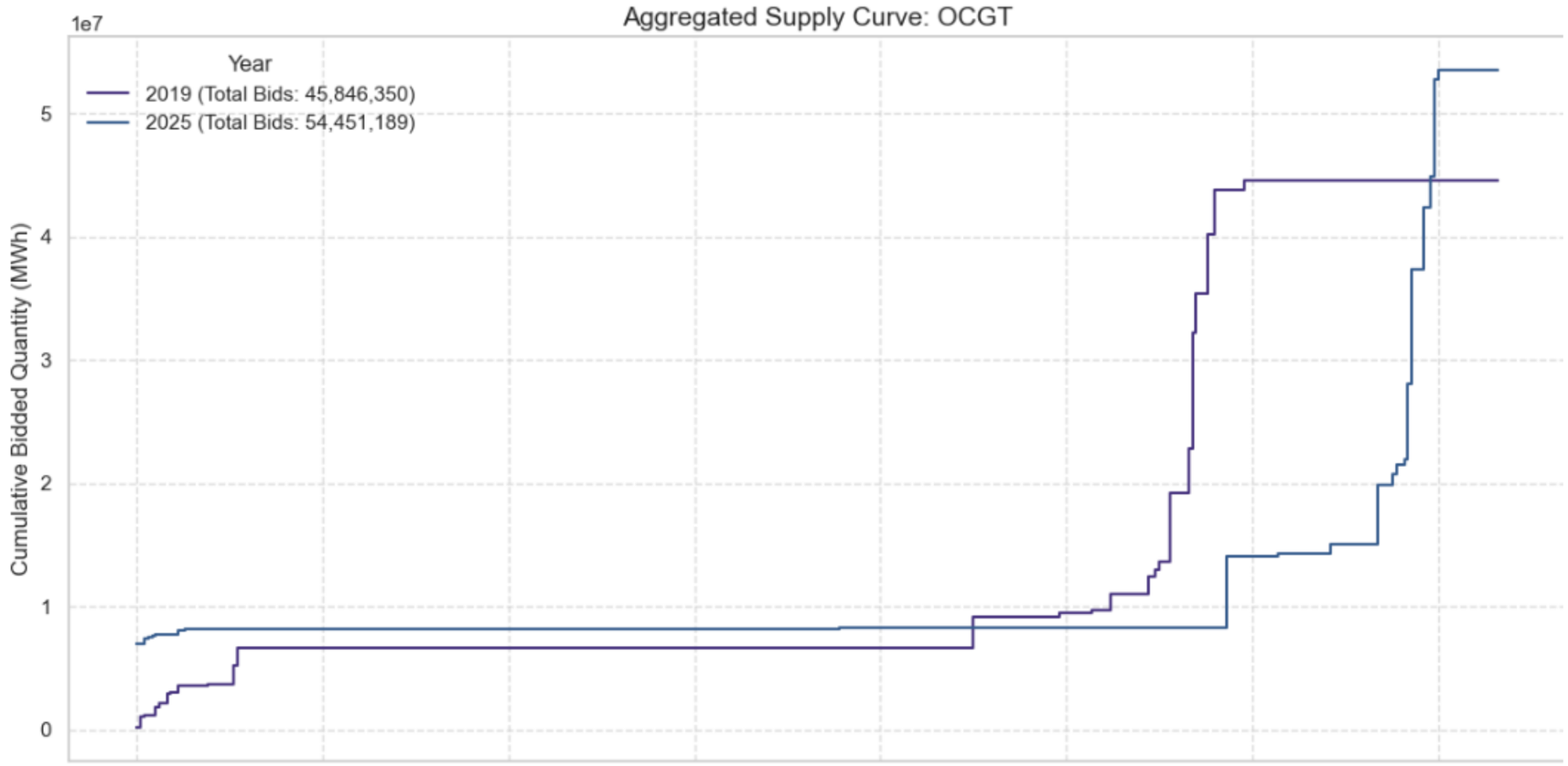
Aggregated Supply Curve: OCGT (2019 vs 2025)

Key Observations

- 2019: Flat at low quantities, steps up at 1,000-5,000 $/MWh; total ~45.8M MWh.
- 2025: Shifts right/up, more quantity at higher prices; total ~54.4M MWh.

Key Interpretation

- Increased Costs/Value: Higher bids reflect rising gas prices or premium for flexibility.
- More Dispatch: Increased quantity shows OCGT's growing role in meeting demand gaps.



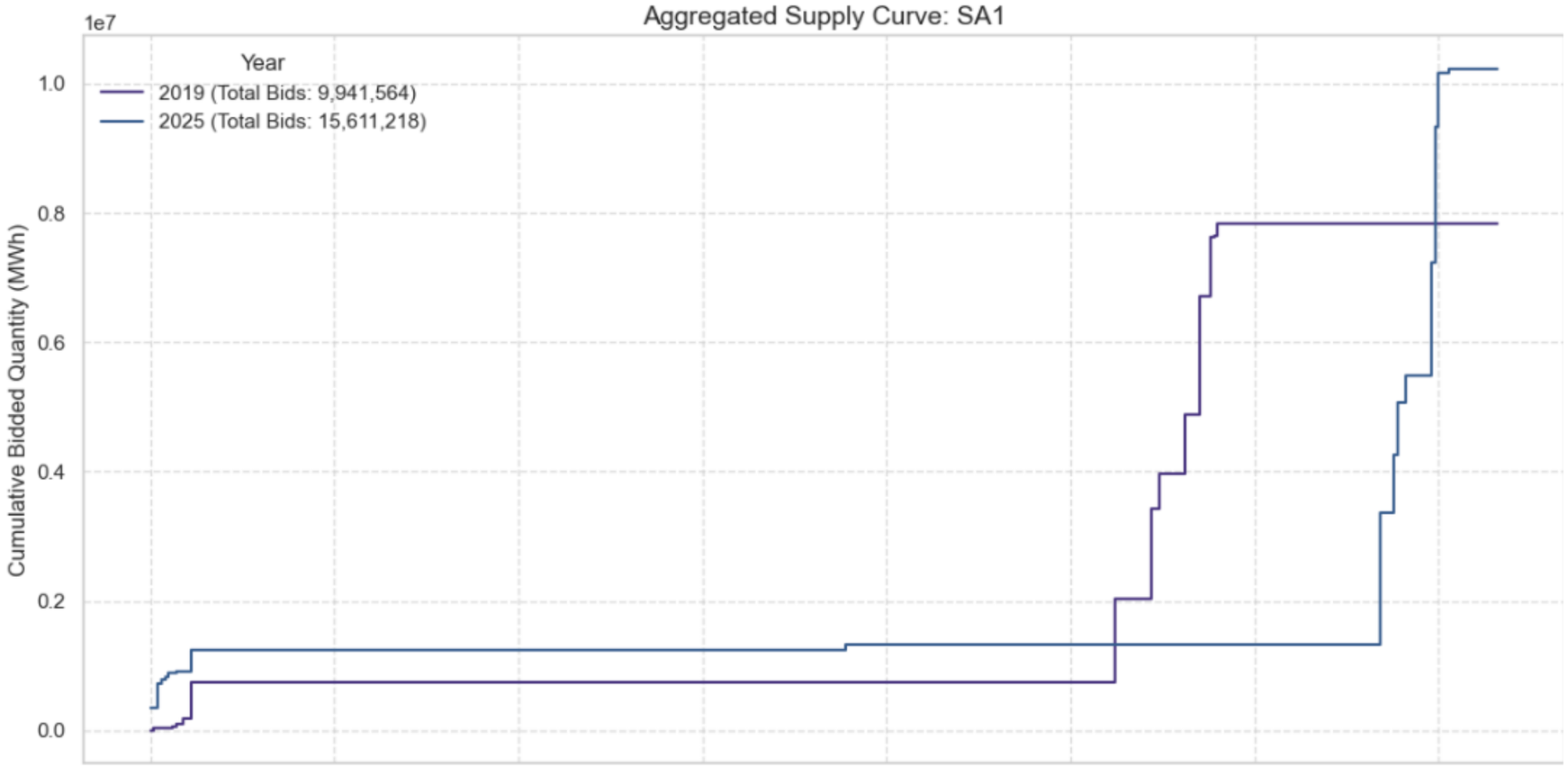
Aggregated Supply Curve: SA1 (South Australia)

Key Observations

- 2019: Steep rise at low prices, flat to ~5-7M MWh, total ~9.94M MWh.
- 2025: Outward shift, more low-price quantity, total ~15.61M MWh.

Key Interpretation

- Significant Solar Growth: The pronounced outward shift and substantial increase in total bidded quantity strongly indicate a massive increase in low-marginal-cost Solar generation in SA1.
- Increased Market Liquidity: More energy is available at very low prices, suggesting a more liquid market.
- Pressure on Thermal: Increased low-cost Solar supply puts significant pressure on OCGT/Black Coal in SA1, likely reducing their dispatch or forcing lower bids.



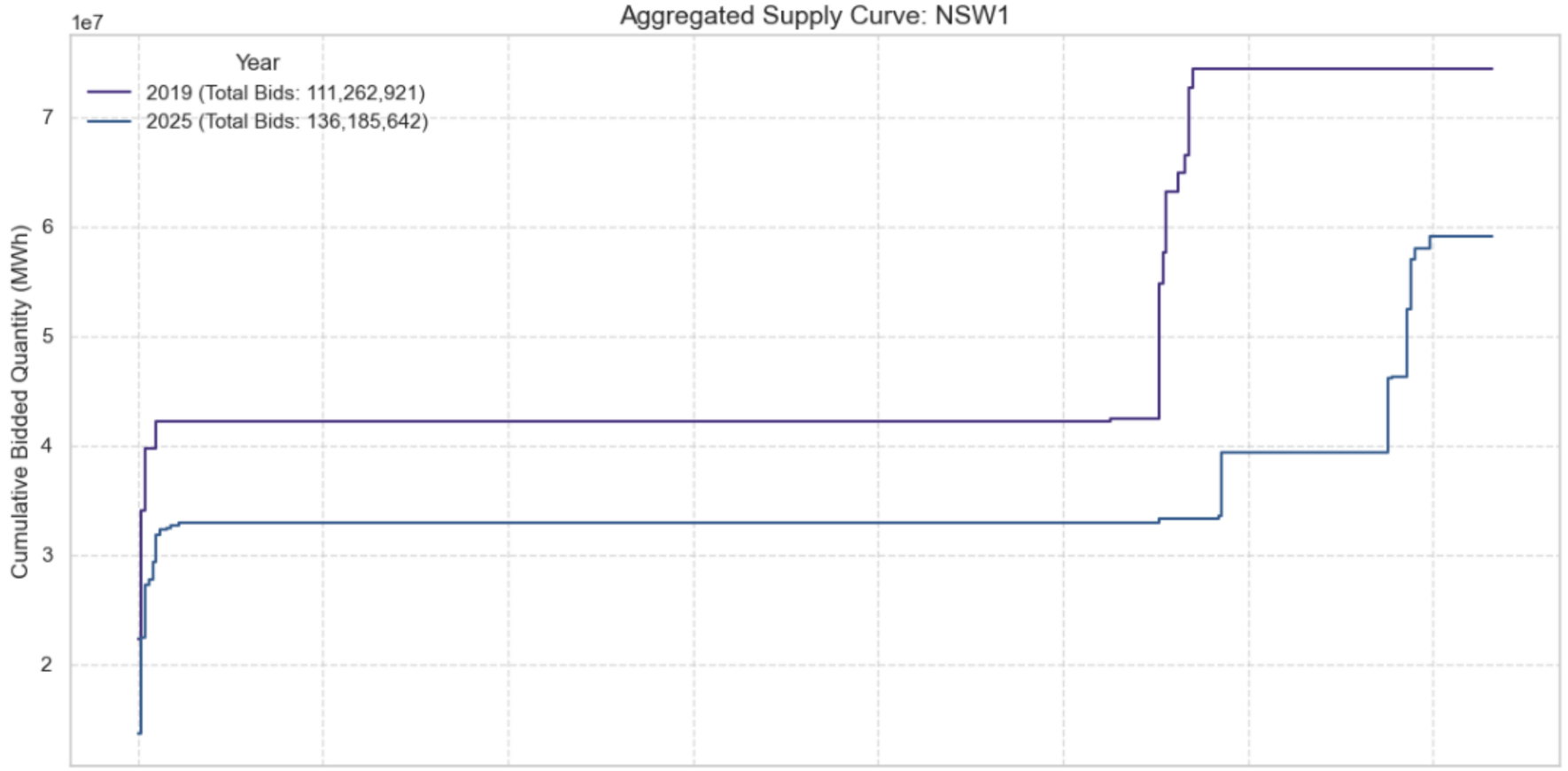
Aggregated Supply Curve: NSW1 (New South Wales)

Key Observations

- 2019: Large low-price quantity, total ~111.26M MWh.
- 2025: Reduced low-price quantity, higher prices for similar quantities, total ~136.18M MWh.

Key Interpretation

- Rising Costs for Dominant Coal: Reduction in quantity offered at lowest prices indicates increased generation costs for NSW1's dominant Black Coal fleet or strategic higher bidding.
- Capacity Expansion at Higher Prices: Total bidded quantity increases, but this new/existing capacity is offered at higher price points.
- Market Pressure: NSW1's curve reflects transition, with declining ultra-low-cost coal leading to overall higher average prices for large quantities of electricity.



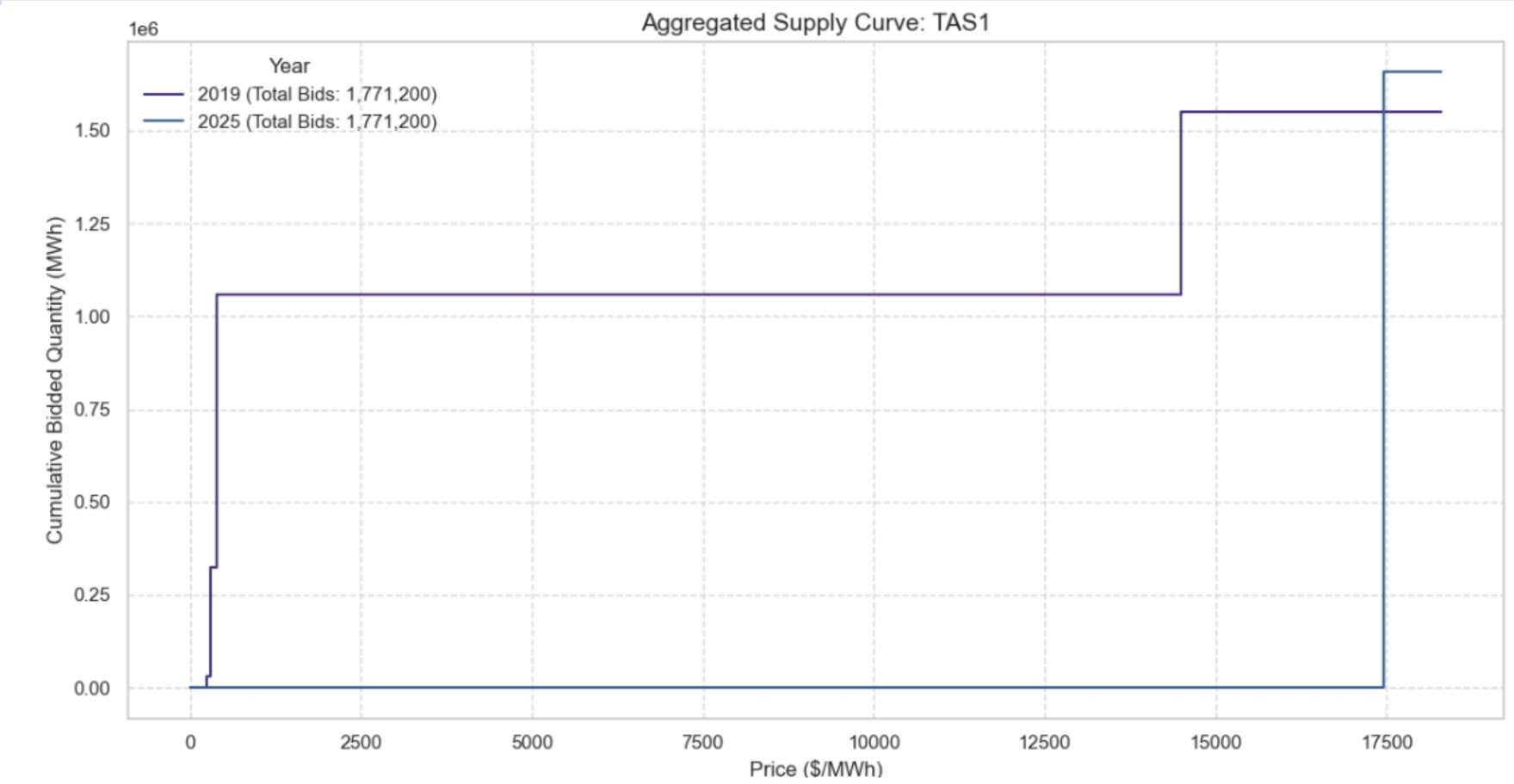
Aggregated Supply Curve: TAS1 (Tasmania)

Key Observations

- 2019: Large low-price block, total ~1.77M MWh.
- 2025: Dramatically reduced low-price quantity, rises to ~1.77M MWh at 17,500 $/MWh.

Key Interpretation

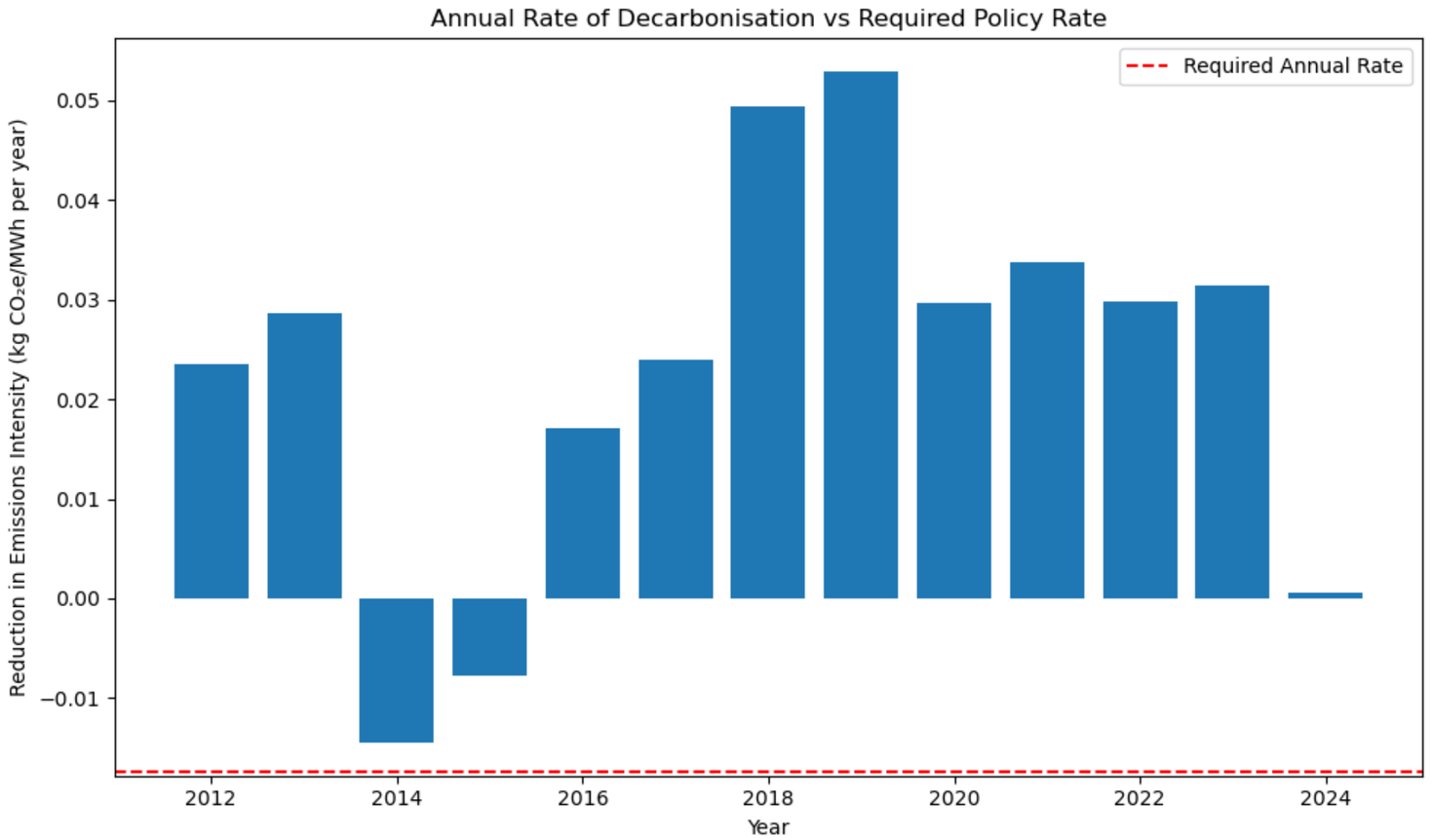
- TAS1's bid volume is predominantly "Non-Renewable" (OCGT/Black Coal), with negligible Solar. This drives the consistent, large low-cost bid block, setting TAS1's thermal units apart from others. They likely bid minimum loads very low.
- High-Price Contingency (OCGT/Black Coal): The more prominent $17,500/MWh segment in 2025 indicates TAS1's OCGT/Black Coal offer increased capacity at market price cap. This suggests heightened demand for last-resort supply/ancillary services or strategic high bids for critical system support.



Australia’s Commitment to Net Zero Emissions

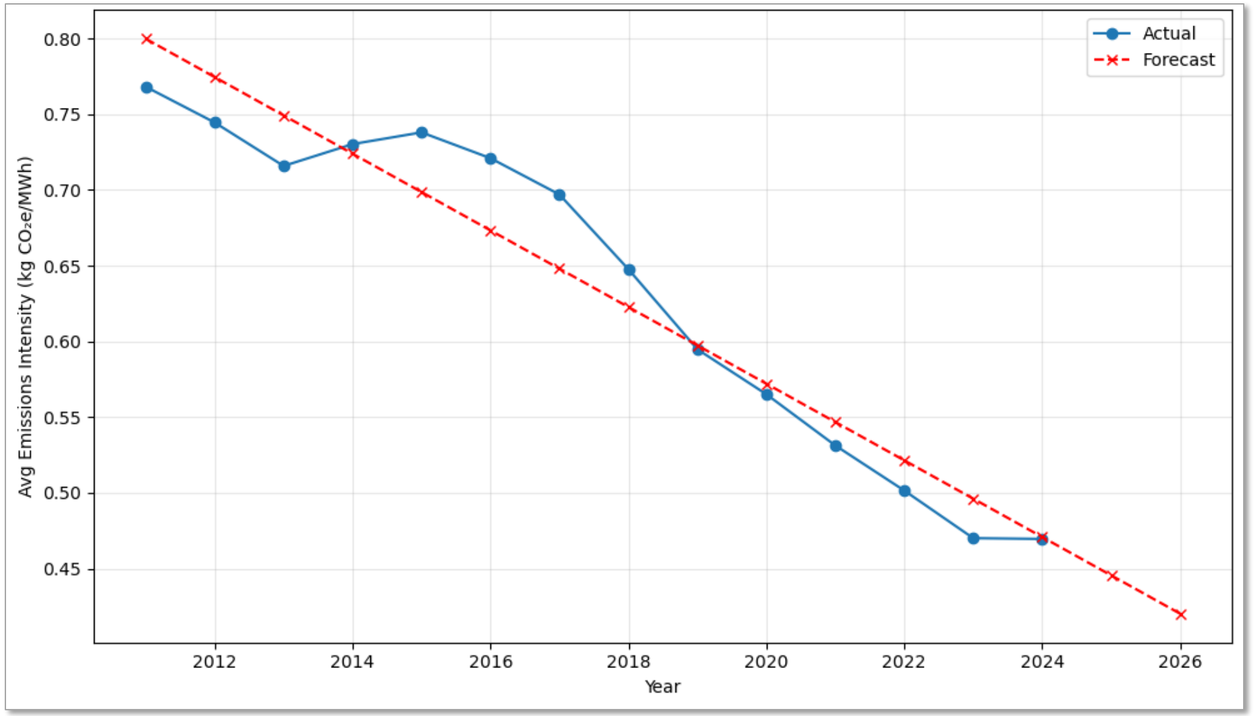
- Australia aims for net zero emissions by 2050 (Paris Agreement).
- Target: 43% emissions reduction from 2005 levels by 2030.
- 82% renewables in the NEM by 2030
- Investment in hydrogen and clean energy
- Electrification of industry and transport
- Safeguard Mechanism strengthened for major emitters.
- States also set ambitious targets to support decarbonization.

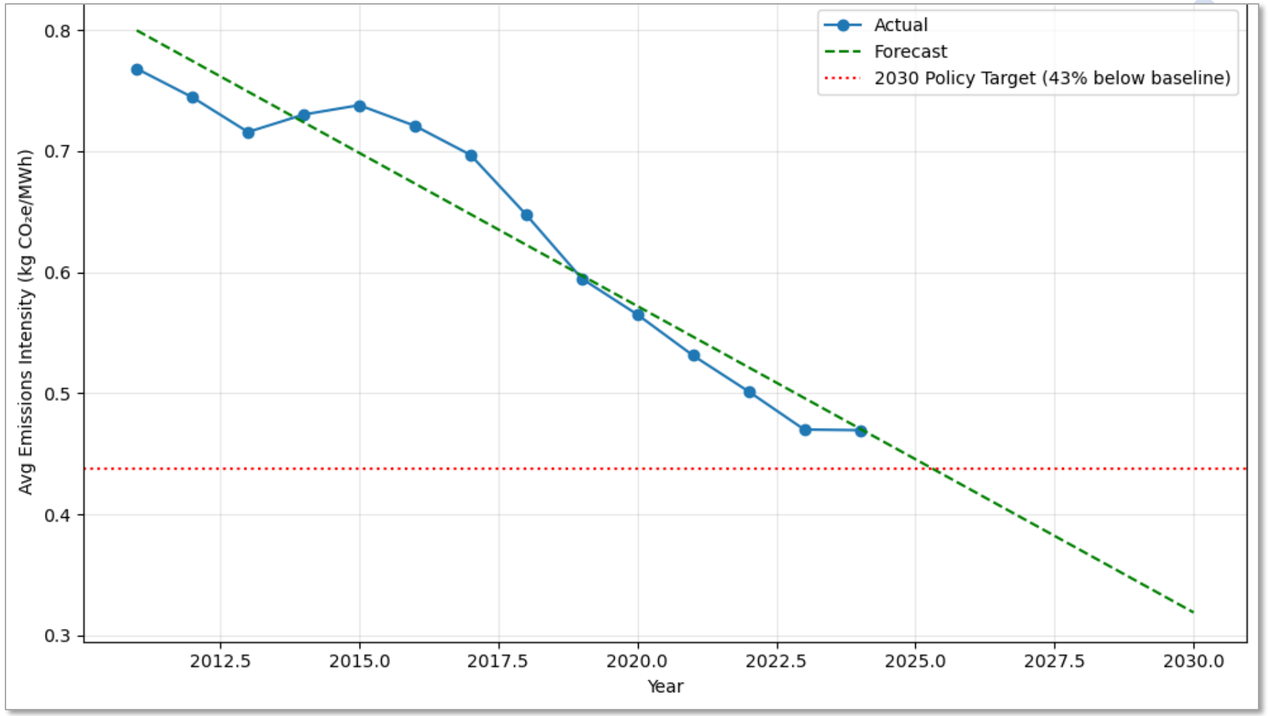
Annual Rate of Decarbonization vs Policy Target



In most years, the annual rate of emissions intensity reduction in the NEM has exceeded the policy rate required to meet Australia's 2030 decarbonization target.

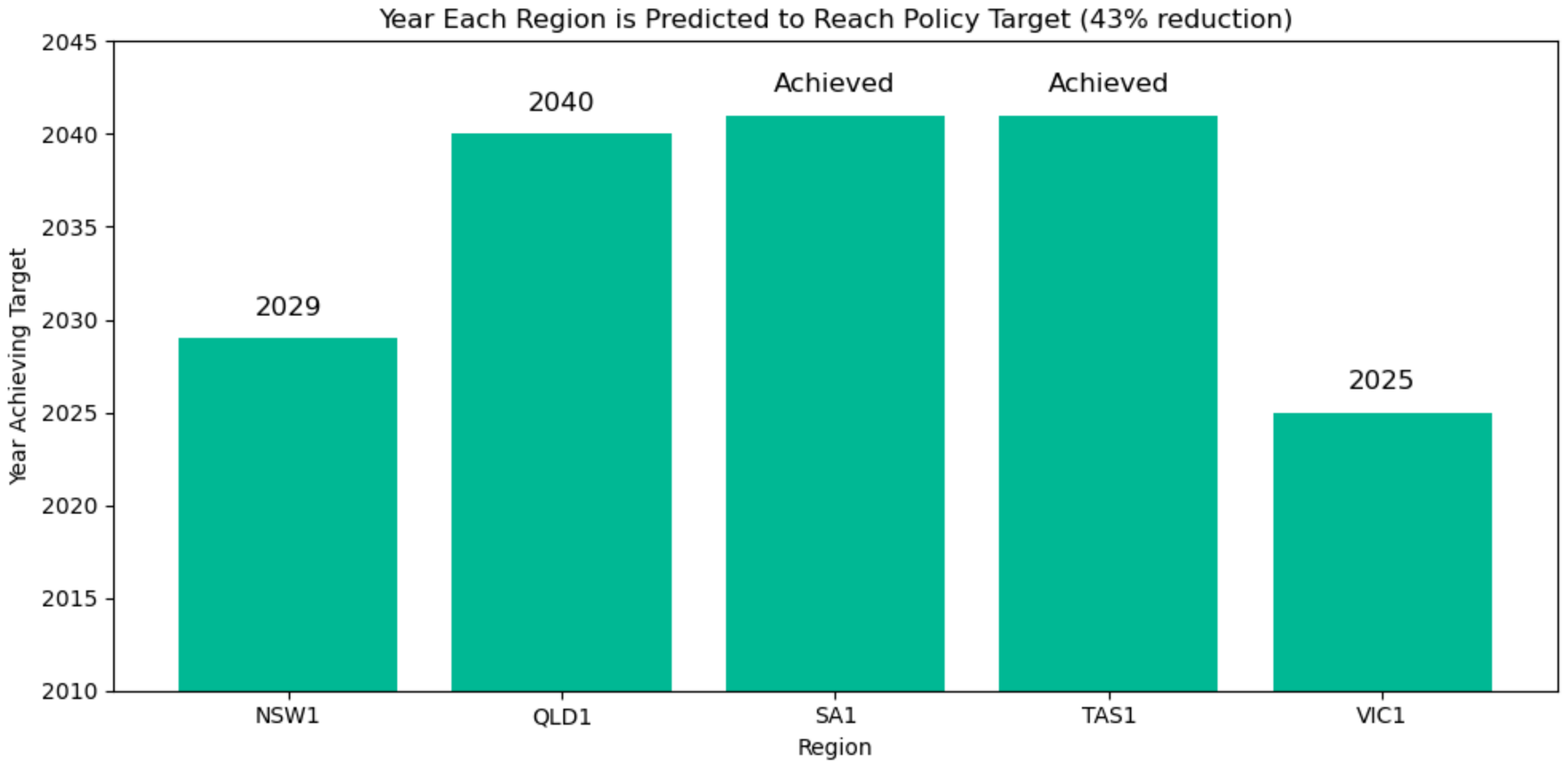
Forecasted NEM Emissions Intensity vs 2030 Policy Target





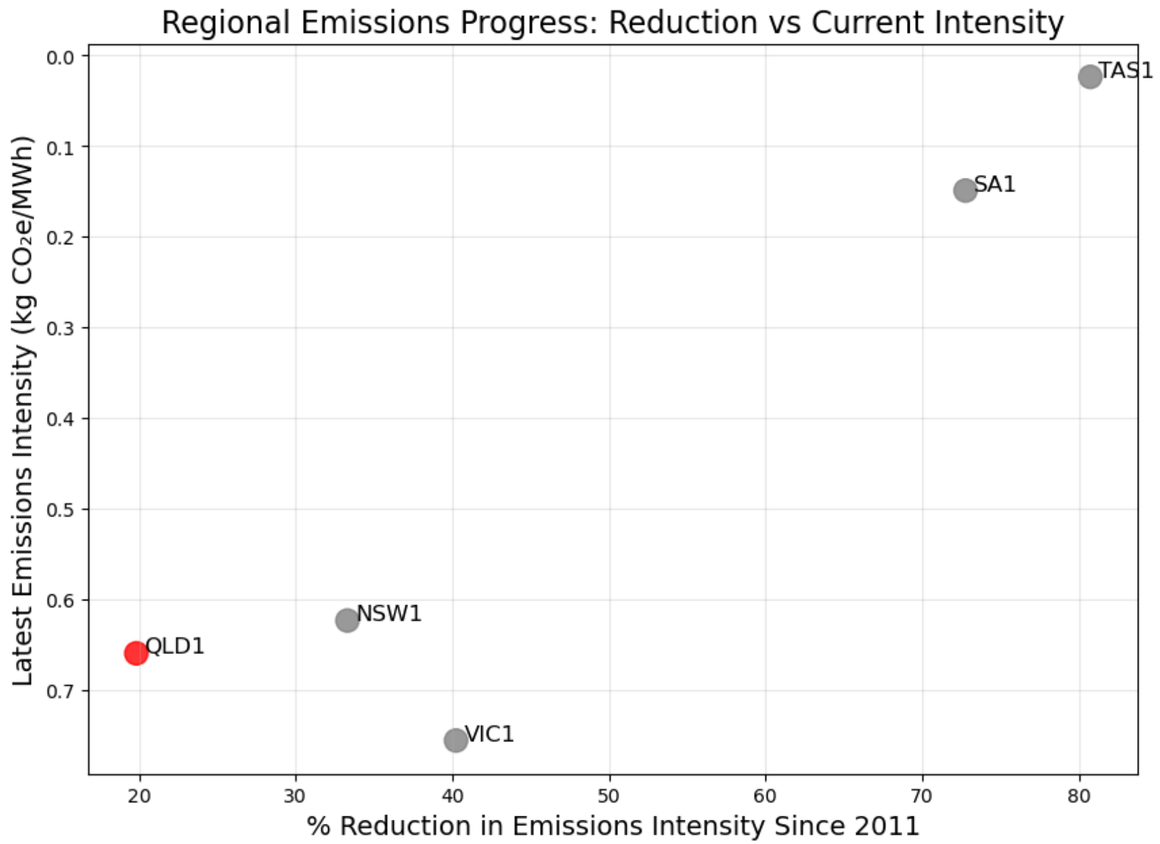
Emissions intensity in the NEM is projected to continue its downward trend, with linear regression forecasting further reductions through 2025. The forecasted decline in NEM emissions intensity suggests that Australia is likely to meet its 2030 policy target, with emissions intensity projected to fall below the required 43% reduction from 2005 baseline levels.

Target Achieving Year for each Region



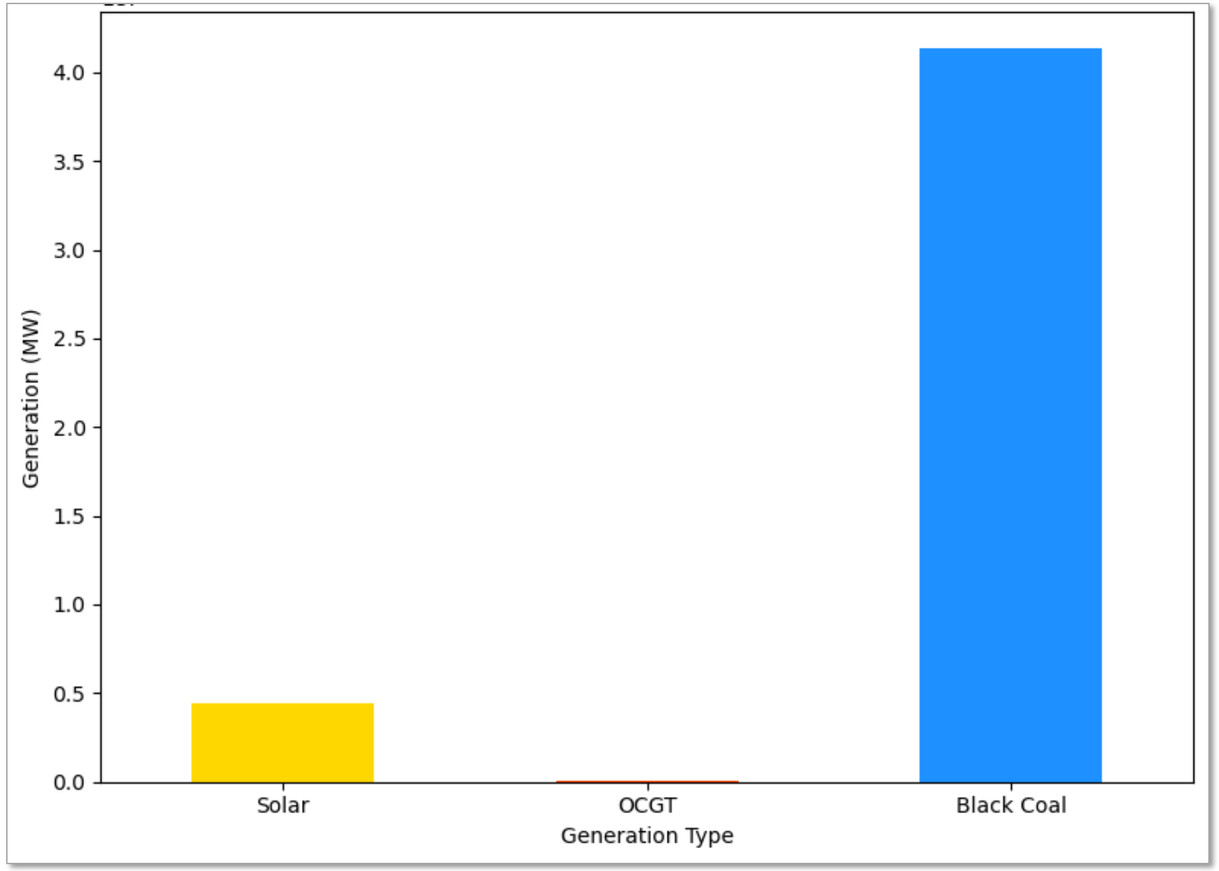
VIC and NSW are predicted to meet the 43% emissions reduction target before 2030, while QLD is projected to reach it by 2040; SA and TAS have already achieved the target.

Region Wise Emission Intensity Reduction Progress



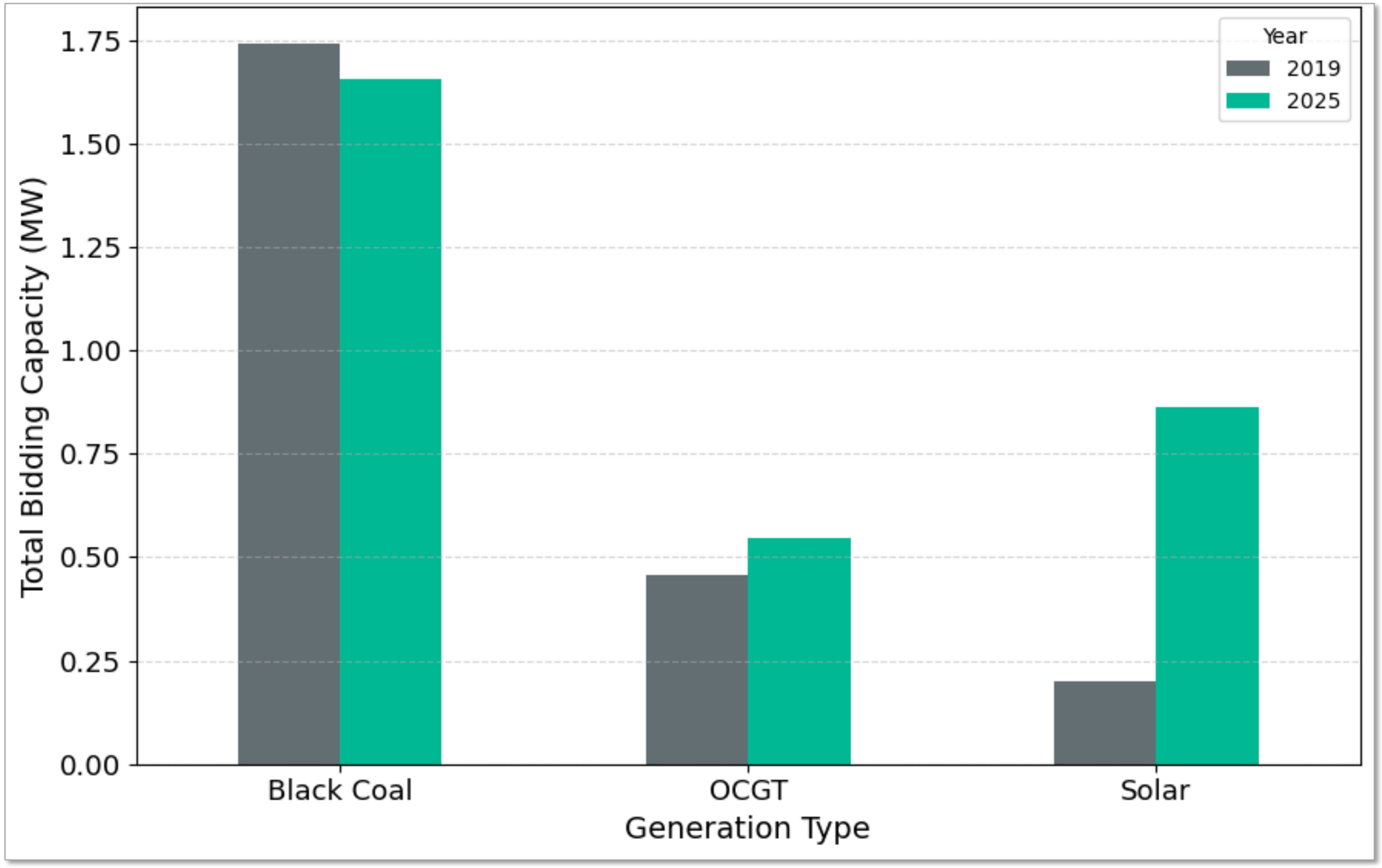
Regions like SA and TAS have achieved the largest reductions in emissions intensity and now operate with the cleanest electricity, while QLD is lagging with both lower reduction and higher current intensity.

Electricity Generated by QLD in April 2025



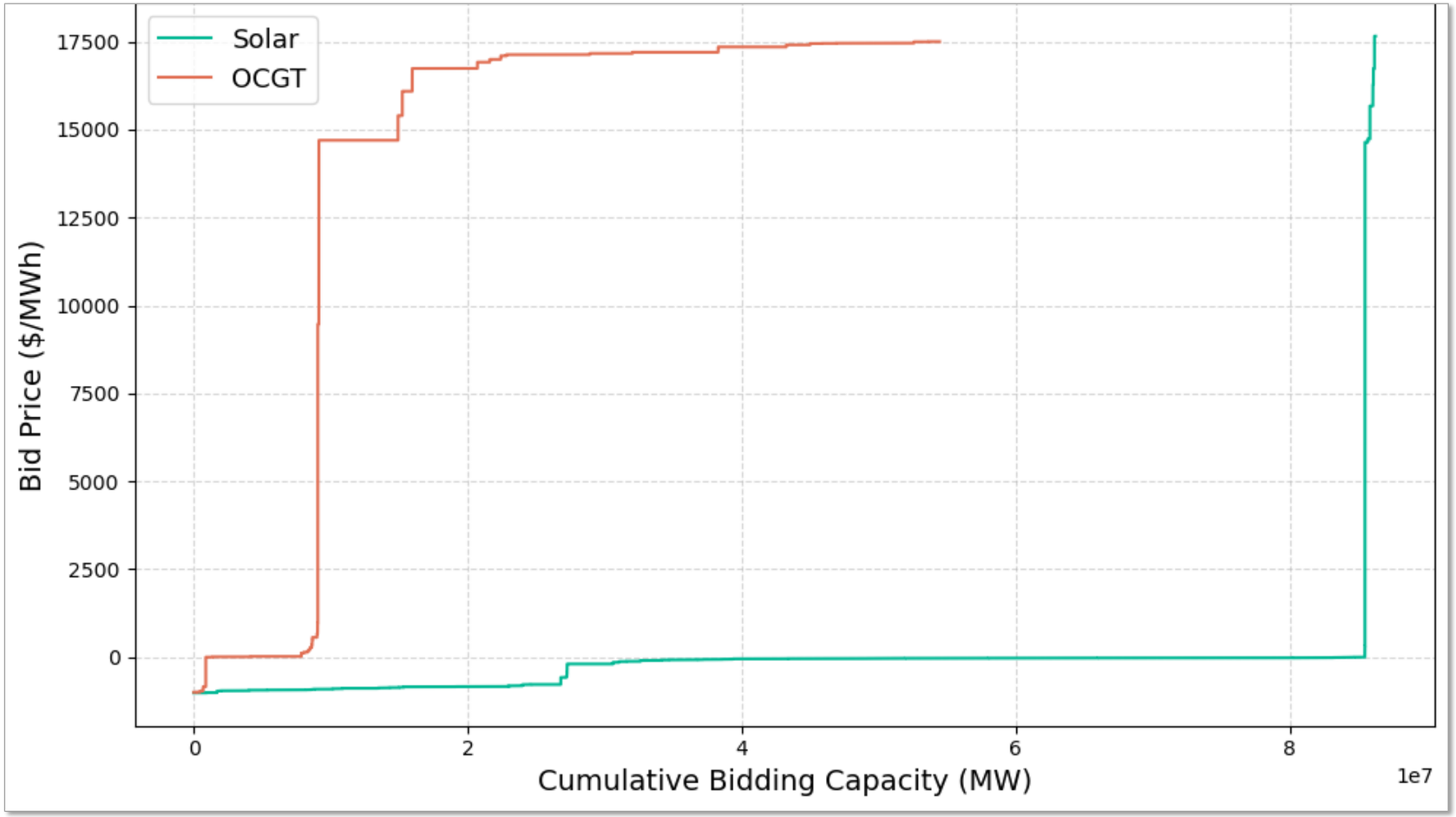
In April 2025, Queensland’s electricity generation was dominated by black coal, with solar making a much smaller contribution and OCGT playing only a minor role.

Market Share by Generation Type in April (2019 vs 2025)



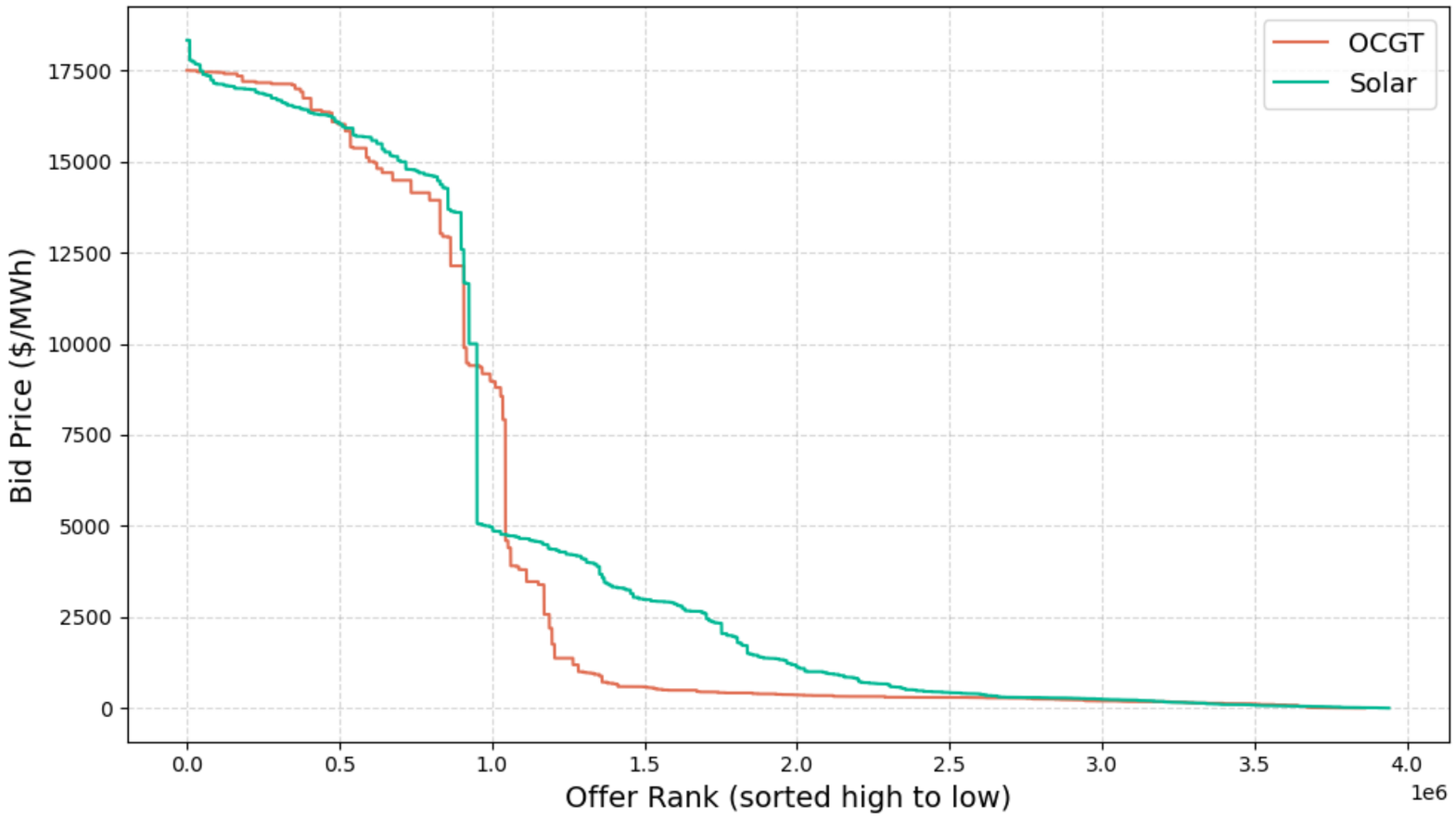
Between April 2019 and 2025, solar and OCGT have significantly increased their market share, while black coal's share has declined.

Aggregated Supply Curve – Solar vs OCGT (April 2025)



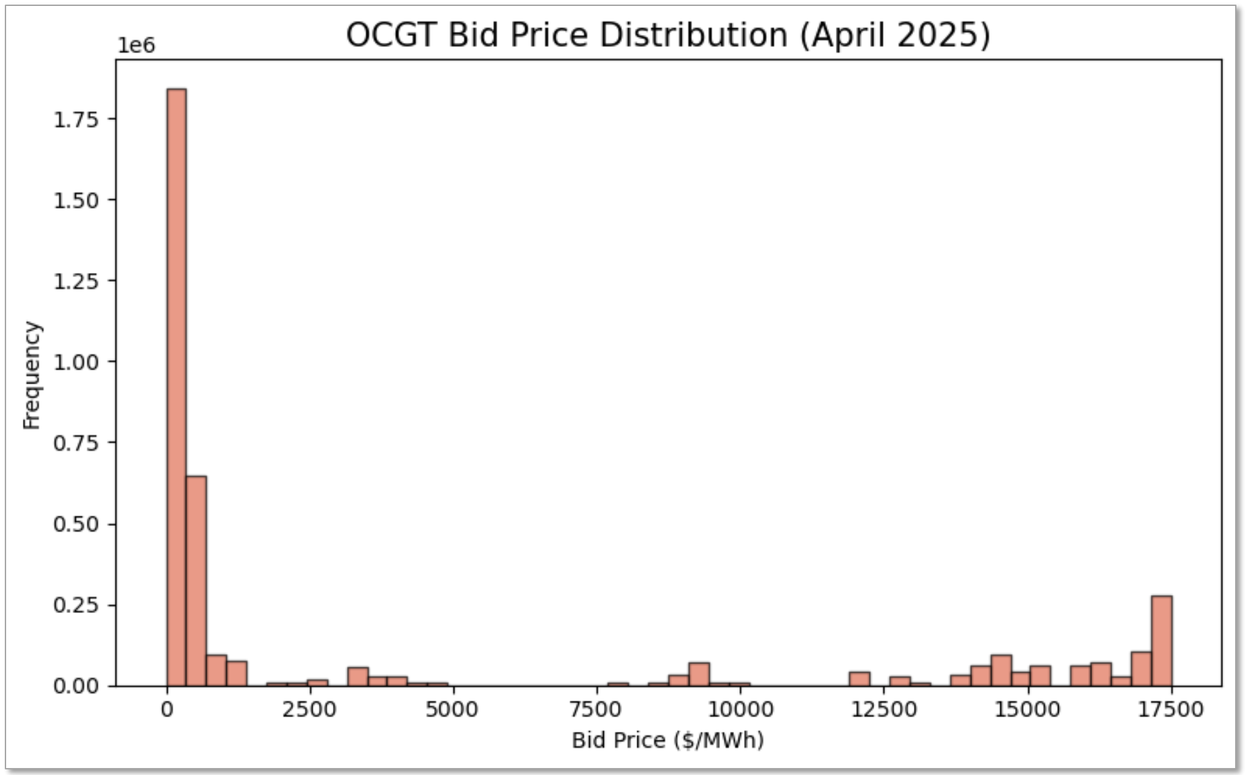
Solar bids dominate the left side of the supply curve with low or zero prices, reflecting their low operating cost.
In contrast, OCGT bids only set prices at much higher levels, entering the market when demand is high or supply is tight.

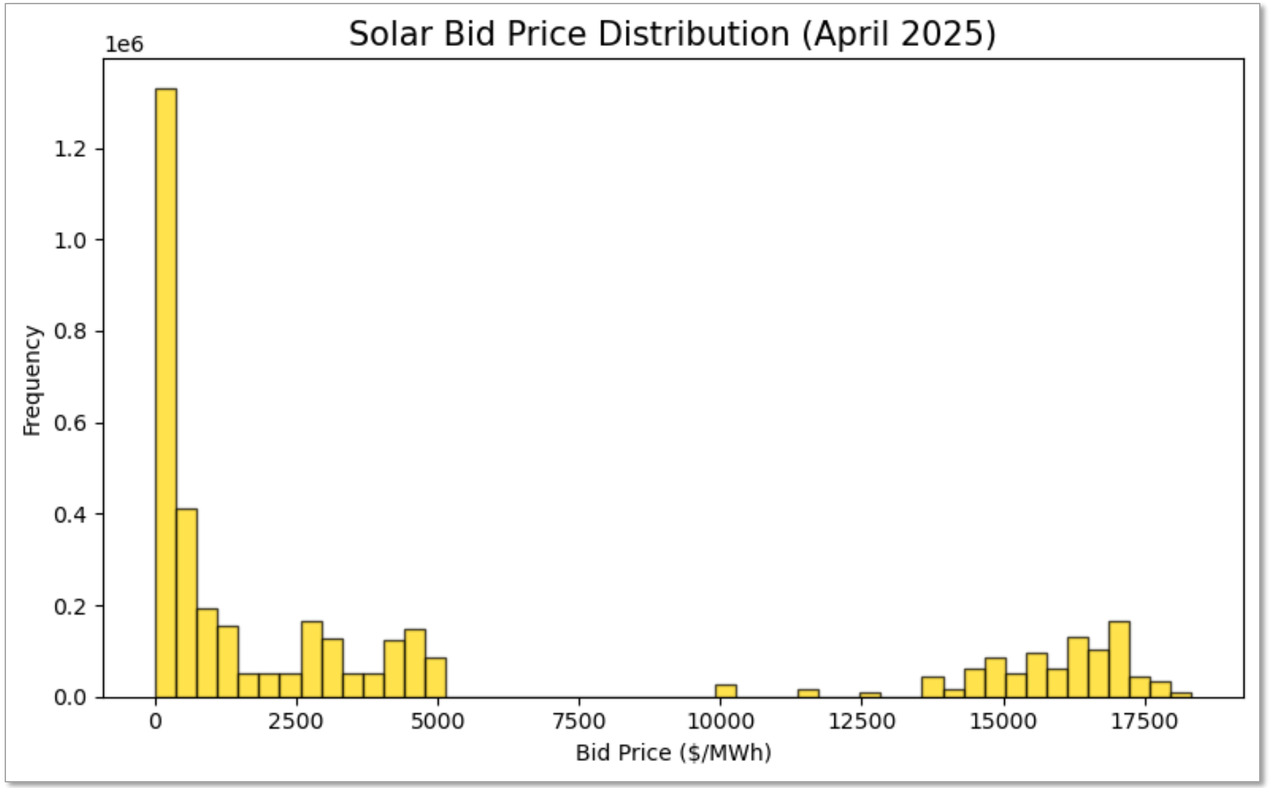
Revenue Duration Curve - OCGT vs Solar (April 2025)



Both OCGT and Solar earn revenue at the highest prices only during a few intervals, but Solar continues to earn revenue across a wider range of lower bid prices. This highlights Solar's ability to capture market value more consistently, while OCGT relies on rare price spikes.

Bid Price Distribution (OCGT vs Solar) – April 2025

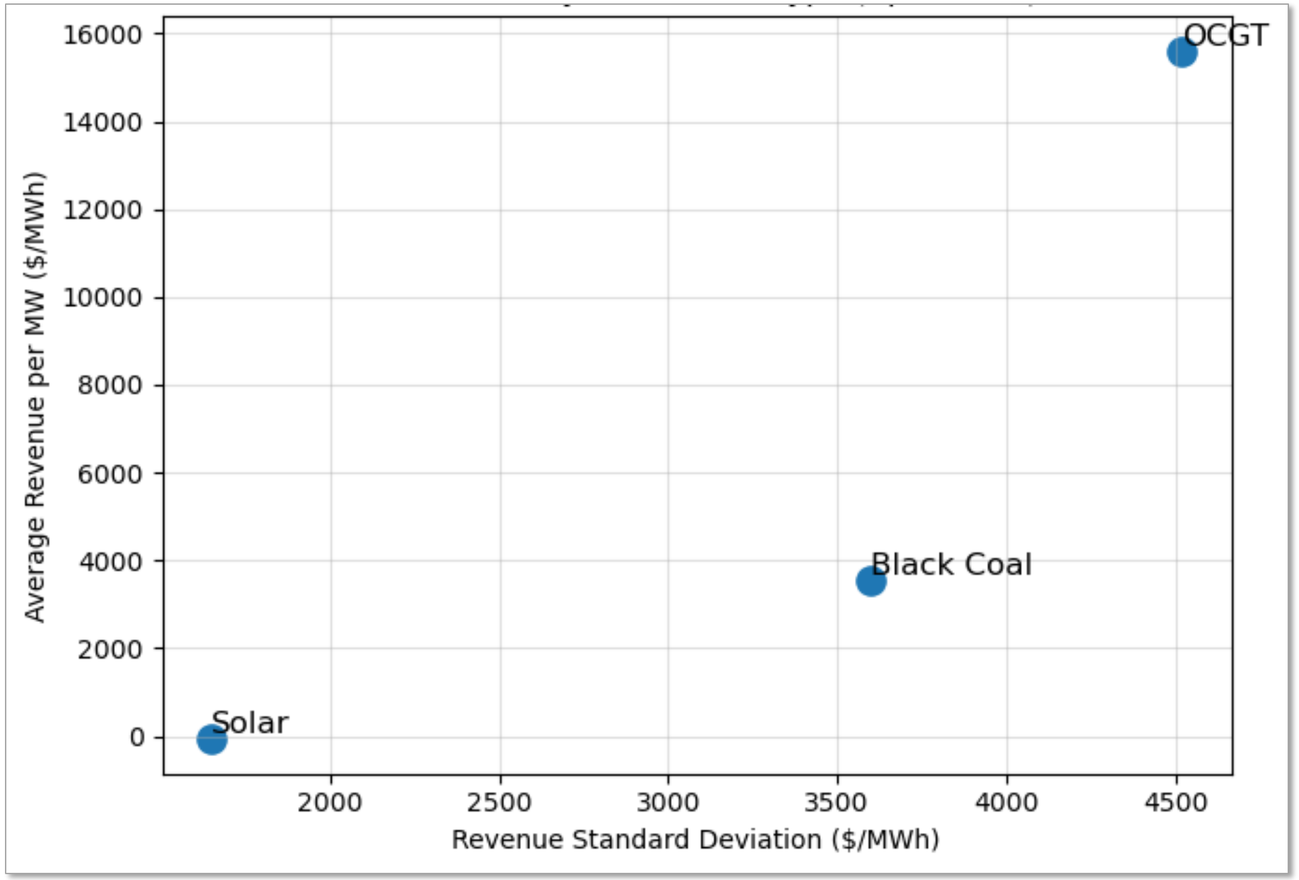




Both OCGT and Solar bids in April 2025 are heavily concentrated at low prices, but each also includes frequent very high-price bids above $10,000/MWh.

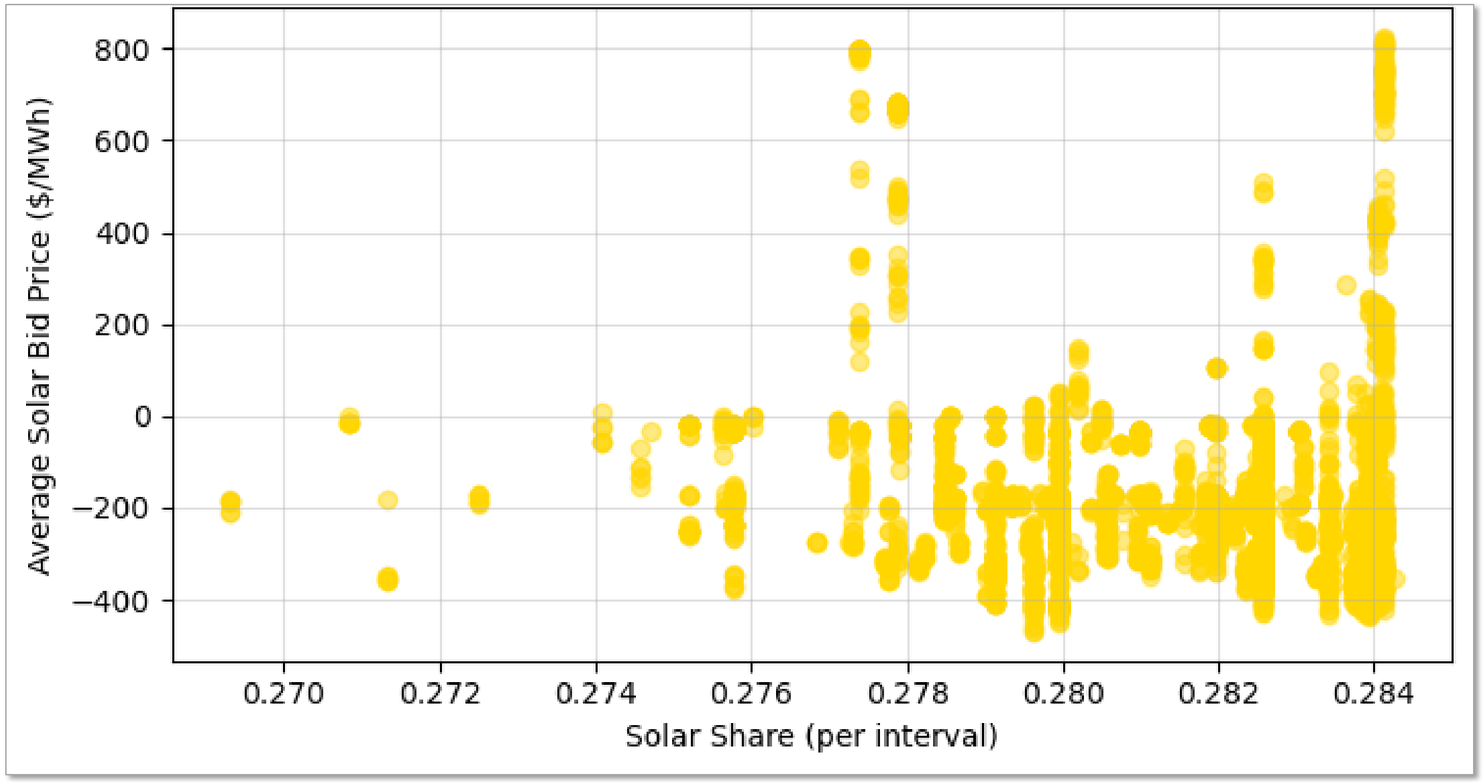
This pattern reflects the mix of low marginal cost operation with strategic high-price offers for both technologies.

Risk Return by Generation Type (April 2025)



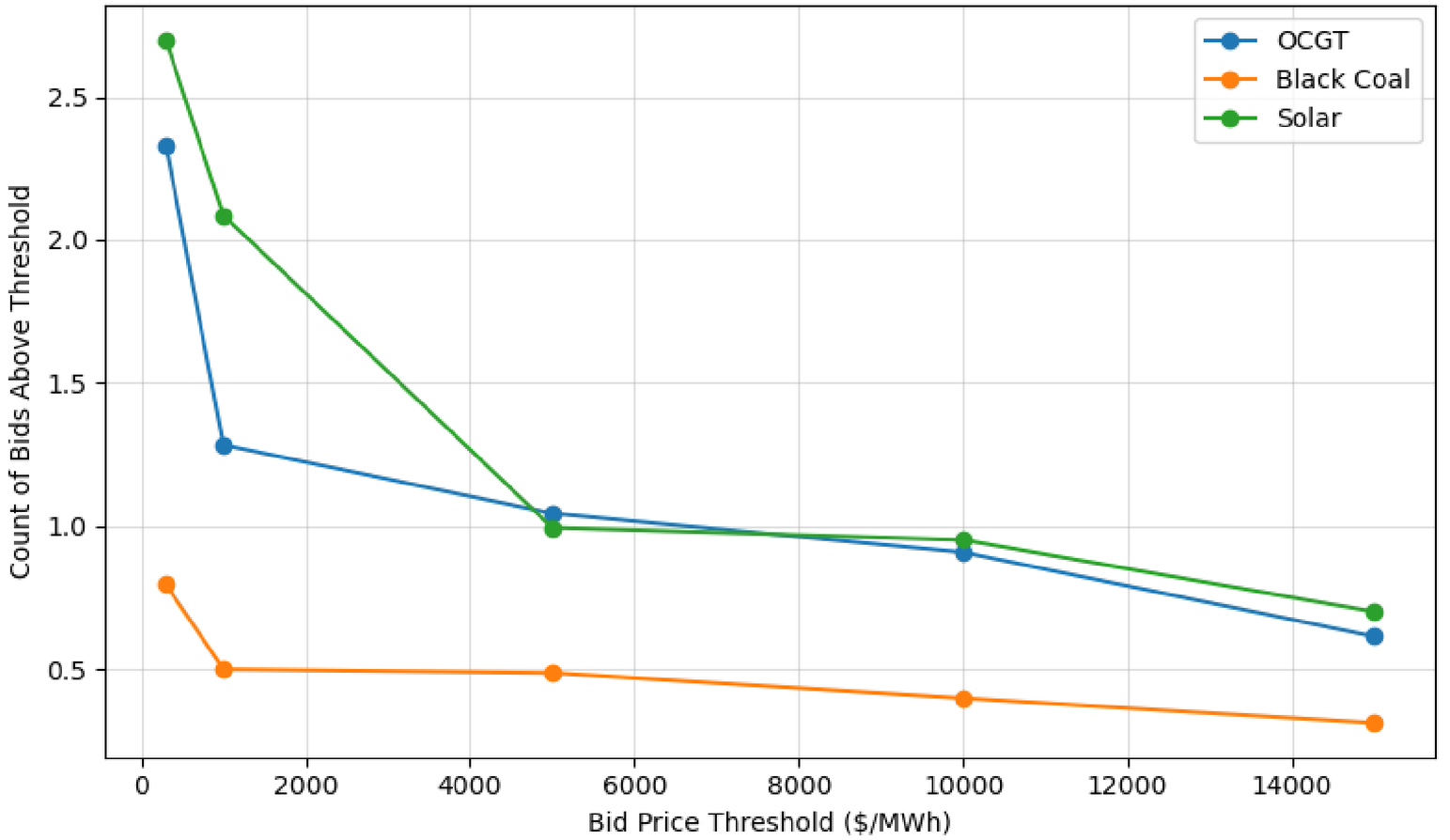
OCGT offers the highest average revenue but comes with the greatest risk (volatility), while solar has low risk but also the lowest returns. Black coal sits in between, balancing moderate risk and moderate returns.

Solar Price Cannibalization (April 2025)



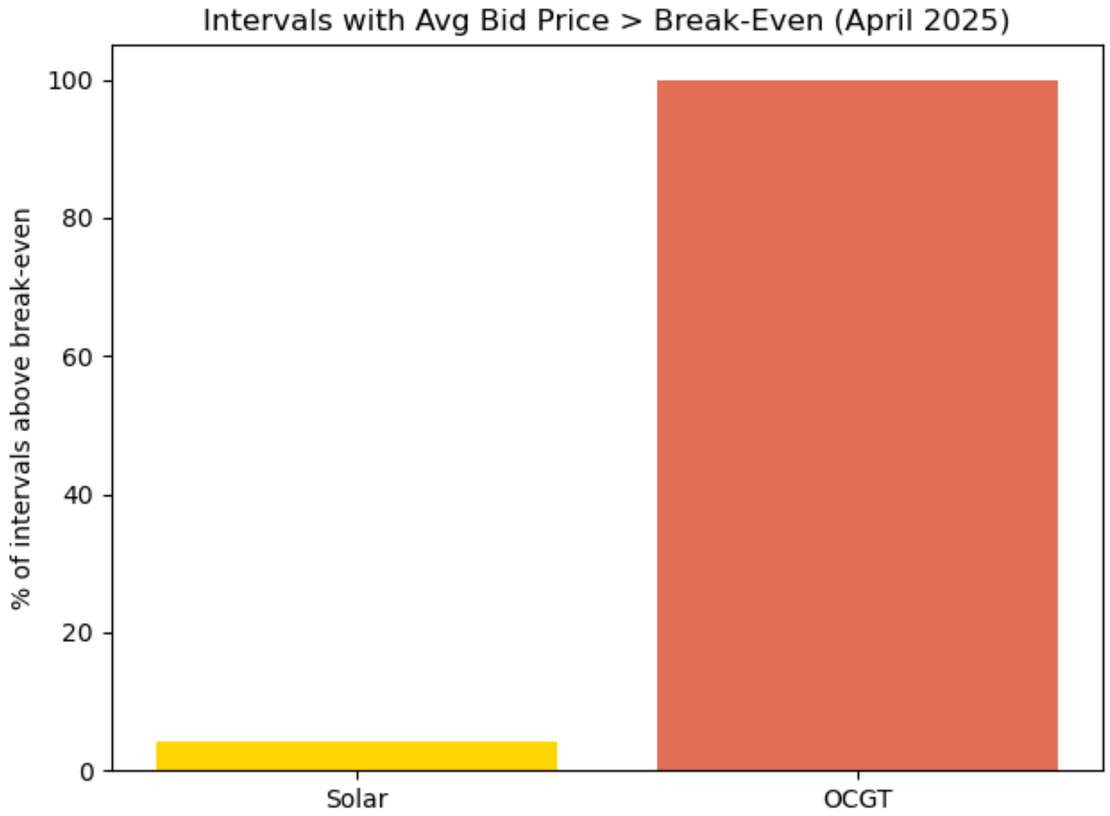
As solar share increases, the average solar bid price tends to fall, highlighting the price cannibalization effect when more solar enters the market.

Revenue Duration Curve by Generation Type (April 2025)



OCGT and solar both place many bids above high price thresholds, while black coal bids are mostly concentrated at lower price levels, reflecting their different market roles.

Break Even Analysis



In April 2025, OCGT cleared its break-even price nearly all the time, while solar cleared in only a small fraction of intervals, underscoring tougher revenue conditions for solar under current market prices.

Investment Insights – Generation Type Comparison

	Solar	OCGT	Black Coal
Market Trend	Rapid growth, strong policy support	Stable or peaking, key support role	Declining, being phased out
Revenue Outlook	Under pressure from price cannibalization; challenging break-even	Profitable during high price spikes; volatile	Revenue stable but shrinking
Risk Profile	Low risk, low average returns	High risk, high reward	Moderate risk, moderate returns
Capacity Factor	Highest in 2025 analysis	Lowest (peaking plant)	Moderate to high
Opportunity	Policy-driven growth, future expansion	Capturing scarcity pricing, grid backup	Short-term market presence
Challenge	Falling marginal revenue, volatility	Uncertain policy outlook, rare events	Regulatory/policy risk, emissions
Recommendation	Attractive long-term, hedge volatility	Good for risk-seeking or grid strategy	Divest or avoid new investment

Key Risks and Opportunities

Risks

- **Solar:** Increased price cannibalization reduces marginal revenue as renewables grow.
- **OCGT:** Relies on rare high-price events; profitability may fall if renewables expand faster or policy shifts.
- **Coal:** Exposed to policy-driven phase-out and emissions regulation.

Opportunities

- **Solar:** Policy targets and falling technology costs support long-term growth.
- **OCGT:** Essential for grid reliability and earns high revenue during price spikes.
- **Coal:** Limited to short-term opportunities as the sector declines.

Strategic Recommendations

- ❑ Prioritize renewable investments (especially solar and wind) to align with Australia’s decarbonization targets and market growth.
- ❑ Consider OCGT for portfolio diversification or exposure to scarcity pricing—but manage risk given market volatility and policy uncertainty.
- ❑ Reevaluate coal positions as phase-out and regulatory risk intensify.
- ❑ Monitor market reforms, policy changes, and technology costs to stay ahead in a rapidly evolving NEM landscape.

Recap

Mohammad Marzan Rahman

Task 1: Track annual emissions intensity and decarbonization progress

Muntasir Md Nafis

Task 2: Compare generation mix and emissions by region

Battogtokh Myagmarjav

Task 2: Compare emissions after Covid & Trello Tracking

Ananya Pandey

Task 3: Identify seasonal trends and generation type contributions

Nikita Farhin

Task 4: Analyse bidding, price, and revenue patterns by generation type

Hassan Mohammed

Task 5: Summarize NEM Emission findings and provide investment recommendations

THANK YOU