# Mid-Semester Memo

# Introduction

This memo explores my locational marginal price (LMP) prediction exploration and process, and my lifecycle analysis (LCA) of all candidate options for our energy portfolio. In the interest of transparency, I have compiled my code for public reference on GitHub at <https://github.com/rmoglen/EnergyDevelopment_Policy>.

# Locational Marginal Price (LMP) Prediction

ERCOT’s [2018 LTSA report](http://www.ercot.com/content/wcm/lists/144927/2018_LTSA_Report.pdf) was central in guiding my LMP predictions, specifically the data presented in its Figure I.1. Figure I.1 in the LSTA was generated by a survey of ERCOT stakeholders. They concluded that the key drivers for the ERCOT grid were Texas economic conditions, natural gas prices, capital costs for renewable energy, environmental regulations, and weather conditions, followed by several less significant drivers. Therefore, I selected natural gas prices, Texas GDP, and renewable energy capital costs as predictors in my model, along with year, load zone, season, and peak versus off peak timing. Table A in Appendix A summarizes the data I used in my model and their sources.

## Scenarios

ERCOT’s [2018 LTSA report](http://www.ercot.com/content/wcm/lists/144927/2018_LTSA_Report.pdf) also provided guidance on scenarios likely to impact the ERCOT grid and thus future prices. Two of the scenarios it discusses are (1) High Economic Growth and (2) High Renewable Penetration. My third scenario was (3) the Base Case. Forecasts for the next 20 years for all my predictors were available except for renewables capital costs, which I extrapolated by fitting an exponential model to the available data.

(1) the Base Case was predicted using the available forecasts data from Table A. For (2) the High Economic Growth scenario, EIA provides its own predictions of natural gas prices under high economic growth, and ERCOT describes an annual Texas GDP increase of 2.2% rather than the 1.4% in the base case. Again, future LMPs were predicted using forecasts as predictors, this time with 2.2% GDP growth and High Economic Growth conditions gas prices in place of the base case numbers. For (3) the High Renewable Penetration, it was assumed that this adoption was driven by lower renewable energy costs, so forecasted renewable energy capital costs were multiplied by a discount factor (assumed to be 0.9). Future LMPs were once more predicted using the forecast data from Table A, with the substitution of the discounted renewable energy capital cost forecasts.

## Aggregation

Historical LMPs were aggregated by season (“summer” as April through October and “non-summer” as the rest of the year) and peak (hours 8 through 23 in the summer and 1 and 24 in the non-summer) and off-peak the rest of the time. This aggregation was done both because the financial models that will use the LMP predictions as inputs will likely not need a finer temporal resolution and because the forecast data available was generally only at 1 year temporal resolution, making finer prediction difficult and likely inaccurate. Historical LMPs in each of the time-categories (summer peak, summer off-peak, non-summer peak, and non-summer off-peak) were averaged by median value in that year, though other functions such as mean or max could be computed, depending on the requirements of downstream models. Therefore, my model predicts the median LMP in each load zone, each year from 2020-2039, in each of the four time-categories.

## Model

I used linear regression to fit a model to LMPs from 2011 to 2019. I then applied this model to 2020 to 2039 to predict future LMPs. My model is of the following form:

Since Category and LoadZone are both categorical variables, they were each broken up into N-1 dummy variables, where N is the number of unique values in that category. The resulting model is summarized in Appendix B.

# Life Cycle Analysis

## CCGT Analysis

The first step in the life cycle analysis of the CCGTs in both Houston in San Antonio was computing their respective capacity factors. Houston offers three candidate turbines, each with their respective heat rates, while the San Antonio site requires analysis of only one turbine. These sites and their respective options are summarized in Table 1 below. The capacity factor of each of these potential projects was assumed to be the average hypothetical capacity factor for the years 2011 to 2019, computed by comparing the turbine’s marginal cost to the LMP in the plant’s location. This implicitly assumes that the plant’s capacity factor for 2011 to 2019 would be the same as from 2020 to 2039. While certainly a simplification, given the coarse aggregation of forecasts (LMP and gas prices) for 2020 to 2039, calculating the capacity factor using these values would fail to capture a gas plant’s ability to spin up and down quickly in response to LMPs. The time resolution of the forecast data is significantly coarse than a gas plant’s spin up time, which is a large part of how natural gas plants stay profitable. It was therefore deemed preferable to extrapolate each turbine’s capacity factor based on 2011 to 2019 gas prices and LMPs.

The capacity factor is the average percentage of time intervals where the LMP exceeds the turbine’s marginal cost. The marginal cost for each turbine was computed using equation (1):

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| --- | --- |
|  | (1) |

The annual total emissions were then estimated using equation (2). Note that there are 8760 hours in a year. These results are shown in Table 2. Note that two values for NOx are reported for the San Antonio plant in Tables 1 and 2, for before and after the SCR is added in 2021 as required by the Clean Air Act.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | | (2) |
|  | | | | | | | |  |
| Table 1: CCGT Life Cycle Analysis Emissions Rate | | | | | | | | |
| **Turbine** | **Location** | **Capacity Factor**  **(2011-2019)** | **Heat Rate (BTU/ kWh)** | **Capacity (MW)** | **NOx**  **(lb/ MMBTU)** | **SO2**  **(lb/ MMBTU)** | **CO2-eq**  **(lb/ MMBTU)** | |
| GE 7FA.05 | Houston | 26.7% | 6800 | 600 | 0.0075 | 0.00074 | 117 | |
| Mitsubishi 501J | Houston | 31.4% | 6400 | 460 | 0.0075 | 0.00074 | 117 | |
| Mitsubishi 501GAC | Houston | 34.4% | 6200 | 405 | 0.0075 | 0.00074 | 117 | |
| GE 207FA.04 | San Antonio | 10.5% | 8840 [2] | 942 | 0.15 / 0.0075\* | 0.00074 | 117 | |
| \* Emissions rates before and after the SCR is added in 2021 as required by the Clean Air Act | | | | | | | | |

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Table 2: CCGT Life Cycle Analysis Annual Emissions | | | | | | | |
| **Turbine** | **Location** | **Capacity Factor**  **(2011-2019)** | **Heat Rate (BTU/ kWh)** | **Capacity (MW)** | **NOx**  **(s.t./year)** | **SO2**  **(s.t./year)** | **CO2-eq**  **(s.t./year)** |
| GE 7FA.05 | Houston | 26.7% | 6800 | 600 | 35.79 | 3.53 | 558253.43 |
| Mitsubishi 501J | Houston | 31.4% | 6400 | 460 | 30.37 | 3.00 | 473726.22 |
| Mitsubishi 501GAC | Houston | 34.4% | 6200 | 405 | 28.38 | 2.80 | 442654.75 |
| GE 207FA.04 | San Antonio | 10.5% | 8840 [2] | 942 | 574.46/  28.72\* | 2.83 | 448076.78 |
| \* Emissions before and after the SCR is added in 2021 as required by the Clean Air Act | | | | | | | |

|  |  |
| --- | --- |
|  | (3) |

Equation (3) can be used to compute water consumption and withdrawal for the candidate CCGT. In this case, [3] as referenced for the consumption and withdrawal rates per MWh for our candidate turbines. [3] lists water rates for several CCGT configurations; the recirculating cooling rates were used in this analysis. Table 3 presents the annual water consumption and usage for the candidate turbines.

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| Table 3: CCGT Life Cycle Analysis Water Consumption and Withdrawal [3] | | | | | | | |
| **Turbine** | **Location** | **Capacity Factor** | **Capacity (MW)** | **Water Consumption\*** | | **Water Withdrawal\*** | |
| **(2011-2019)** | **(gal/MWh)** | **(10^6 gal/year)** | **(gal/MWh)** | **(10^6 gal/year)** |
| GE 7FA.05 | Houston | 26.70% | 600 | 200 | 280.67 | 250 | 350.84 |
| Mitsubishi 501J | Houston | 31.40% | 460 | 200 | 253.06 | 250 | 316.32 |
| Mitsubishi 501GAC | Houston | 34.40% | 405 | 200 | 244.09 | 250 | 305.11 |
| GE 207FA.04 | San Antonio | 10.50% | 942 | 200 | 173.29 | 250 | 216.61 |
| \* Assumed recirculating cooling (cooling towers) | | | | | | | |

## Renewables Analysis

The renewables Life Cycle Analysis is conducted similarly to the CCGT Life Cycle Analysis. Using the values provided in the case study for the seasonal capacity factors, the annual weighted capacity factor was calculated, presented in Table 4. Then, using theCO2-eq emissions rates for each source’s production provided in [4], the annual CO2-eq emission rate was calculated using equation (3).

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| Table 4: Renewables Life Cycle Analysis [4] | | | | | | |
| **Development** | **Source** | **Capacity Factor** | **Capacity** | **Project Area** | **CO2-eq** | |
| **(MW)** | **(acres)** | **(g CO2-eq/kWh)** | **(kg CO2-eq/yr)** |
| Big Sky | Solar | 0.328 | 250 | 8000 | 55 | 39.48 |
| XIT Ranch | Onshore Wind | 0.495 | 250 | 38000 | 13 | 14.10 |
| Lavaca | Coastal Wind | 0.484 | 200 | 20000 | 13 | 11.02 |
| Lavaca | Coastal Wind | 0.446 | 150 | 20000 | 13 | 7.62 |

# References

1. 7F.04 Gas Turbine. (2020). Retrieved 26 October 2020, from <https://www.ge.com/power/gas/gas-turbines/7f-04>
2. eGrid. (2018). Retrieved 26 October 2020, from <https://www.epa.gov/egrid/download-data>
3. Macknick, et al. (2012). Environ. Res. Lett
4. National Renewable Energy Laboratory. (2013). *Life Cycle Greenhouse Gas Emissions from Electricity Generation*. Retrieved from https://www.nrel.gov/docs/fy13osti/57187.pdf

# Appendix A: Data Sources

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| --- | --- | --- | --- | --- |
| Table A: Data Sources | | | | |
| **Name** | **Source** | **Notes** | **Date Range** | **Time Resolution Downloaded** |
| Historical SPP | [ERCOT](http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13061&reportTitle=Historical%20RTM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey) |  | 2011-2019 | 15 minutes |
| Historical Temperature | [NOAA](https://www.ncdc.noaa.gov/cdo-web/datatools/lcd) | Houston Airport | 2011-2020 | 1 hour |
| Temperature Forecasts | [USGS](http://regclim.coas.oregonstate.edu/visualization/rccv/states-counties/) | Texas-wide Used, Mean Model Used | 2020-2099 | 10 years |
| US Natural Gas Price Forecasts | [EIA](https://www.eia.gov/outlooks/aeo/data/browser/#/?id=13-AEO2018&cases=ref2018&sourcekey=0) | Industrial Used | 2016-2050 | 1 year |
| Historical US Natural Gas Price | [EIA](https://www.eia.gov/dnav/ng/hist/n3035us3A.htm) | Monthly available, Industrial Used | 1997-2019 | 1 year |
| Historical and Forecasted Peak and Annual Demand | [ERCOT](http://www.ercot.com/content/wcm/lists/114580/2017_Long-Term_Hourly_Peak_Demand_and_Energy_Forecast.pdf) | Extrapolate for 2027-2039, not yet included in model | 2007-2026 | 1 year |
| Historical Texas GDP | [US Bureau of Economic Development](https://fred.stlouisfed.org/series/TXNGSP) |  | 1997-2019 | 1 year |
| Texas GDP Forecasts | [ERCOT](http://www.ercot.com/content/wcm/lists/144927/2018_LTSA_Report.pdf) | Growth rate applied to 2019 GDP | 1.4% growth (normal), 2.2% (high) | 1 year |
| Capacity-Weighted Average Renewable Costs | [EIA](https://www.eia.gov/electricity/generatorcosts/) | Extrapolate exponentially for years outside range, past and future | 2013-2018 | 1 year |

# Appendix B: LMP Model Summary

Coefficients:

Estimate Std. Error t value Pr(>|t|)

(Intercept) 3.103e+03 3.747e+02 8.281 1.20e-15 \*\*\*

Year -1.550e+00 1.866e-01 -8.308 9.79e-16 \*\*\*

categorynon-summer peak -2.368e+00 1.632e-01 -14.510 < 2e-16 \*\*\*

categorysummer off-peak -1.913e+00 1.632e-01 -11.723 < 2e-16 \*\*\*

categorysummer peak 5.843e+00 1.632e-01 35.808 < 2e-16 \*\*\*

ZoneHB\_HOUSTON 5.061e-01 3.065e-01 1.651 0.099325 .

ZoneHB\_HUBAVG -5.944e-02 3.065e-01 -0.194 0.846296

ZoneHB\_NORTH 4.819e-02 3.065e-01 0.157 0.875117

ZoneHB\_PAN -2.310e+00 6.970e-01 -3.314 0.000988 \*\*\*

ZoneHB\_SOUTH 2.040e-01 3.065e-01 0.666 0.505928

ZoneHB\_WEST -4.525e-01 3.065e-01 -1.476 0.140490

ZoneLZ\_AEN 2.593e-01 3.065e-01 0.846 0.397947

ZoneLZ\_CPS 4.303e-01 3.065e-01 1.404 0.160996

ZoneLZ\_HOUSTON 5.972e-01 3.065e-01 1.949 0.051923 .

ZoneLZ\_LCRA 2.594e-01 3.065e-01 0.846 0.397694

ZoneLZ\_NORTH 1.503e-01 3.065e-01 0.490 0.624133

ZoneLZ\_RAYBN 2.969e-01 3.065e-01 0.969 0.333104

ZoneLZ\_SOUTH 3.749e-01 3.065e-01 1.223 0.221898

ZoneLZ\_WEST 5.083e-01 3.065e-01 1.659 0.097853 .

NG\_Price 4.700e+00 1.332e-01 35.297 < 2e-16 \*\*\*

GDP 1.360e-05 2.199e-06 6.187 1.31e-09 \*\*\*

Solar\_PV\_Cost -1.857e-03 3.694e-04 -5.028 6.99e-07 \*\*\*

Onshore\_Wind\_Cost 3.491e-03 1.456e-03 2.397 0.016901 \*

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Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1