ADEC7406.02 - Natural Gas Consumption Forecasting Models

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Abstract

Natural gas is an increasingly prominent energy source in the United States. The war in Ukraine and subsequent sanctions on Russia have affected the international natural gas market, increasing prices. Technical progress indexes and industrial production capabilities have been demonstrated to negatively affect levels of natural gas consumption (Du, B., Guo, X., Wang, A., & Duan, H., 2023). To investigate the effect that these elements, international and domestic, have on natural gas consumption in the US, several forecasting models were generated in this report. A regression model, using the previously mentioned factors as predictor variables, an ETS, ARIMA, and an aggregate model were generated and assessed for their forecasting accuracy. The results of this report are as follows: (a) natural gas consumption in the US has been steadily increasing throughout the 21st century and looks to continue in the short term. (b) US natural gas consumption is largely tied to electricity use and is highly seasonal, with spikes in the winter and peak of summer. (c) Technical progress negatively affects the consumption of natural gas as more advanced and sustainable energy sources become implementable. (d) International market forces have little to no effect on US domestic consumption within the timeframe analyzed in this report. Therefore, this report suggests that natural gas will likely act as a stepping stone energy source between coal and oil and renewable sources like solar and wind. As technical progress continues to improve renewable energies and make them cost-effective and scalable, natural gas consumption should decrease.

Introduction & Significance

Combating climate change and ensuring the long-term health of the planet is a monumental undertaking. Opinions are strongly held and tend to differ on all aspects of this topic, from its existence to minute policy details. US policy, administered through the EPA, has been to invest in and incentivize the natural gas industry as a stepping stone toward more sustainable energy solutions. Natural gas CO2 emission levels are estimated to be half that of coal, among other advantages. (EIA, 2022) However, it is also scrutinized by those preferring to see investments go towards cleaner, renewable sources, like wind and solar. While these criticisms are valid, existing research indicates that as technical progress advances, making renewable energies implementable, natural gas consumption should decrease (Du, Guo, X., Wang, A., & Duan, H., 2023). Regardless, it remains a prominent energy source for wealthy nations like the US because, while the necessary technology is advanced, the industry is robust and capable of producing large amounts of energy. In the US, in particular, there is an abundance of natural gas reservoirs, making it a profitable export. The war in Ukraine and subsequent sanctions on Russia have dramatically increased the demand and willingness to pay for US natural gas in the EU, resulting in a price increase. Furthermore, regardless of the greater context of climate and international politics, energy forecasting is logistically important, as they are needed to allocate resources accurately. (Ravnik, J., & Hriberšek, M., 2019) All this considered, understanding US natural gas consumption past and future trends is important to the climate, the energy sector, and international politics.

Methods

Data

This list highlights the monthly data used and where it was obtained:

- Consumption - EIA
- Average US Temperature - NOAA
- Price (Henry-Hub Index) - EIA
- Exports (Qty) - OECD
- Percent of GDP spent on R&D - OECD
- Industrial Production - OECD

This data was aggregated into a single time-series from 2017 through the end of 2021.

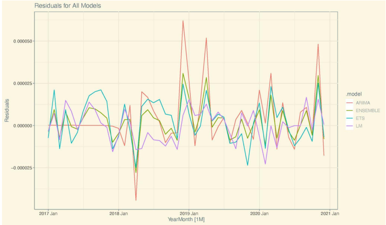
Model Preparation

In order to generate the best possible forecasting models, the time-series needed to be transform. Multiple transformations were tested, including seasonal adjustment and differencing. However, a Box-Cox transformation proved to be the optimal choice, as this yielded a stationary (KPSS test p-value >= 0.1) and positive time-series. Then, the time-series was split into train (2017-2020) and test (2021) sets.

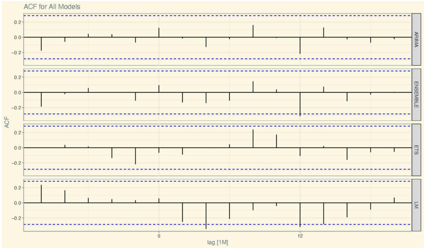
Model Generation

A linear regression model, using temperature, price, exports, R&D spending, and industrial production as predictor variables was generated. Next, automatically optimized ETS and ARIMA models were also generated. Finally, all three models were averaged into an aggregate model.

Residual Analysis



Residuals for all models:
- Largely uniformly distributed
- Some areas of concern: especially spring of 2018

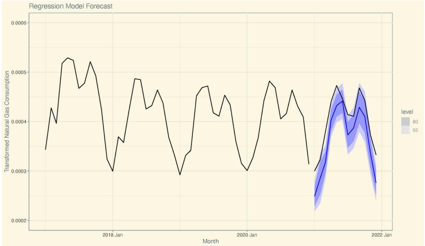


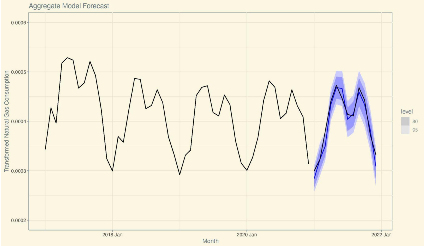
ACF plots look relatively good for all models, with some concern in the linear regression model, which peaks at lag 8 and 12, likely due to the seasonality of our time series. Regardless, the diagnostics look good enough to proceed with forecasting.

Results

Forecasts

For the sake of space, only the regression and aggregate forecast model sis below. However, the unshown ETS and ARIMA forecasts perform well.





Point-Forecast Accuracy

Model	MAE	RMSE	MAPE
Aggregate	0.00001180854	0.00001445880	3.084647
ETS	0.00001414246	0.00001685545	3.633852
ARIMA	0.00001443864	0.00001952111	3.675588
Regression	0.00003872393	0.00004121570	10.151830

As we can see from the metrics in the table above, all models except for the regression performed well. If we consider MAPE, the ETS and ARIMA forecasts were only ~3.6% different than the actual values. The aggregate model performed best overall, with its forecasts only differing from the actuals by ~3%.

Prediction-Interval Accuracy

Model	CRPS
Aggregate	0.000008529201
ETS	0.000010106096
ARIMA	0.000011087096
Regression	0.000029005234

According to the continuous ranked probability score (CRPS), a metric of prediction interval accuracy, our models rank the same as point-forecast accuracy, with the aggregate model being the best and regression the worst.

Discussion

Optimal Model

The aggregate model performs the best. The ETS and ARIMA models are univariate but forecast well within the analyzed time frame. The regression model is multivariate and incorporates external factors that have been proven to affect natural gas consumption levels in other research. While the regression model does not perform as well as the others for the time-series analyzed in this report, it may perform better over a longer time frame. Therefore, the optimal model is the aggregation of all three: ETS, ARIMA, and regression.

Utility

Forecasting energy demand and consumption is important in ensuring adequate power distribution and accessibility. For natural gas logistics planners, an ETS, ARIMA, or ensemble of both models, would assist in understanding how to allocate natural gas effectively. For analysts trying to understanding macroeconomic patterns of natural gas consumption, the model generated in this report would be beneficial.

Conclusion

Natural gas is preferable fossil fuel to coal and oil, given its lower emissions and abundance, making it a facet of climate change action. As the US progresses technologically, and enhances the implementability of renewable energies, natural gas consumption should decrease. However, as the forecasts in this model indicate, that decrease has not begun.

References

Du, B., Guo, X., Wang, A., & Duan, H. (2023). Driving factors and decoupling analysis of natural gas consumption in major Organization for Economic Cooperation and Development countries. Science progress, 106(3), 368504231180783. https://doi.org/10.1177/00368504231180783

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