# Supplementary Information to Significant Impact of the Covid-19 Pandemic on Methane Emissions Evaluated by Comprehensive Statistical Analysis of Satellite Data

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## ABSTRACT

The COVID-19 pandemic has significantly influenced various aspects of society, including environmental factors such as methane emissions. This study investigates the changes in methane concentrations in Seoul, South Korea, from 2019 to 2023, using TROPOMI satellite data and rigorous statistical analyses. By employing analysis of variance (ANOVA) and post-hoc tests (Bonferroni correction, Tukey's HSD, Scheffe's method), the study identifies significant differences in methane levels across different years. The results reveal no significant difference in methane concentrations between 2019 and 2020, but a noticeable increase in methane levels post-2021, correlating with the "new normal" policy implemented in South Korea. This suggests that changes in industrial activities and transportation patterns due to the "new normal" have contributed to higher methane emissions. Student's t-test and Welch's t-test validate these findings, indicate the impact of socio-economic changes on methane emissions. Additionally, the results from the Shapiro-Wilk (S-W) and Kolmogorov-Smirnov (K-S) tests indicate that the sample data can be considered to come from a normal distribution, with the S-W test showing better discriminative power. This study provides a robust quantitative assessment of the pandemic's impact on methane levels and sets a methodological statistical approach for future research in the environmental research community.

## Monte Carlo simulation results for normality testing of satellite data

Monte Carlo simulations were conducted to estimate the Type I and Type II error rates and the power of two statistical tests: the Shapiro-Wilk (S-W) and Kolmogorov-Smirnov (K-S) tests. The simulation begins by generating data under both the null hypothesis and the alternative hypothesis, followed by calculating the test statistics and p-values. Subsequently, the Type I error rate, Type II error rate, and statistical power are computed based on the simulation results. The Type I error rate represents the probability of rejecting the null hypothesis when it is actually true. The Type II error rate indicates the probability of failing to reject the null hypothesis when it is actually false. The power of the test is defined as the probability of correctly rejecting a false null hypothesis, thereby avoiding a Type II error.

Monte Carlo simulations are conducted with a sample size of 60, a significance level of 0.05, and 10,000 iterations to provide a robust estimate of error rates. In this simulation, the null hypothesis assumes a normal distribution, while the alternative hypothesis assumes a uniform distribution.

Figures 1, 2, and 3 present the results of the Monte Carlo simulation analysis for data collected before, during, and after the COVID-19 pandemic. The pre-pandemic data spans from January 2019 to early January 2020. The data from the pandemic period covers late January 2020 to July 2021. The post-pandemic data encompasses the period from August 2021 to December 2023. Table 1 summarizes the results of the Monte Carlo analysis for normality tests conducted during each of these periods using the K-S and S-W tests.

The test statistic histograms in Figures 1, 2, and 3 (left panels) can be interpreted by examining the overlapping area between the blue histogram (null hypothesis) and the orange histogram (alternative hypothesis). A smaller overlap indicates a higher likelihood of avoiding Type II error, thus implying greater discriminative power. Across all analyzed data, the S-W method consistently demonstrates superior discriminative power compared to the K-S method. The highest statistical power observed is 0.8668 for the S-W method and 0.4002 for the K-S method in the pre-pandemic data. In the p-value histograms on the right panels of Figures 1, 2, and 3, the dashed red line indicates the significance level or critical value (0.05). The orange-colored p-value histogram (alternative hypothesis) for the S-W method shows a substantial area below the red line, suggesting a high likelihood of failing to reject the alternative hypothesis. Conversely, the blue histogram (null hypothesis) ideally has an area up to 1, indicating a failure to reject the null hypothesis. Based on this Monte Carlo simulation analysis, it can be concluded that all data originate from a normal distribution, confirming the validity of t-tests and ANOVA analyses for these data

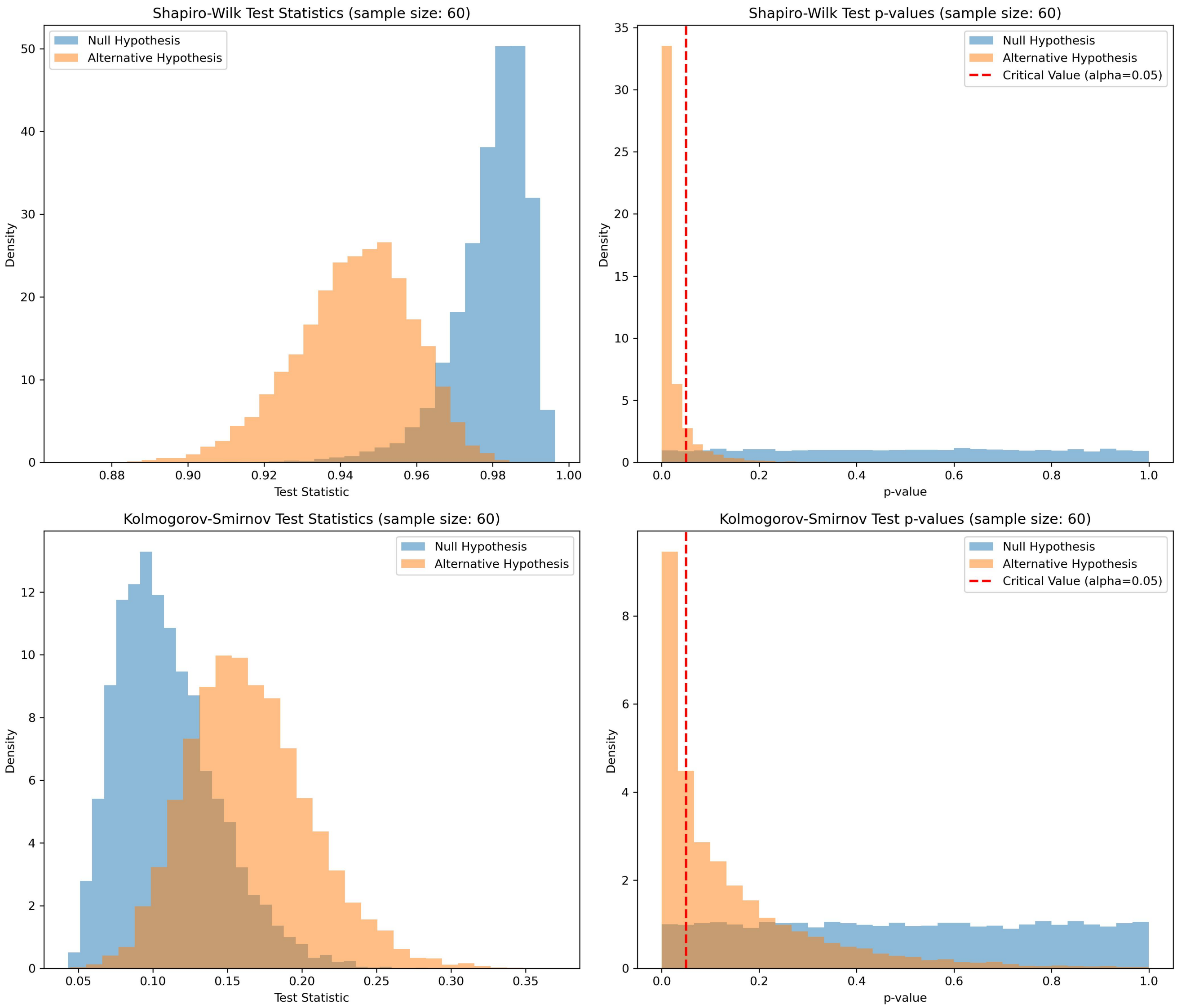


**Figure 1.** Monte Carlo simulation results for normality testing of satellite data prior to the COVID-19 pandemic.

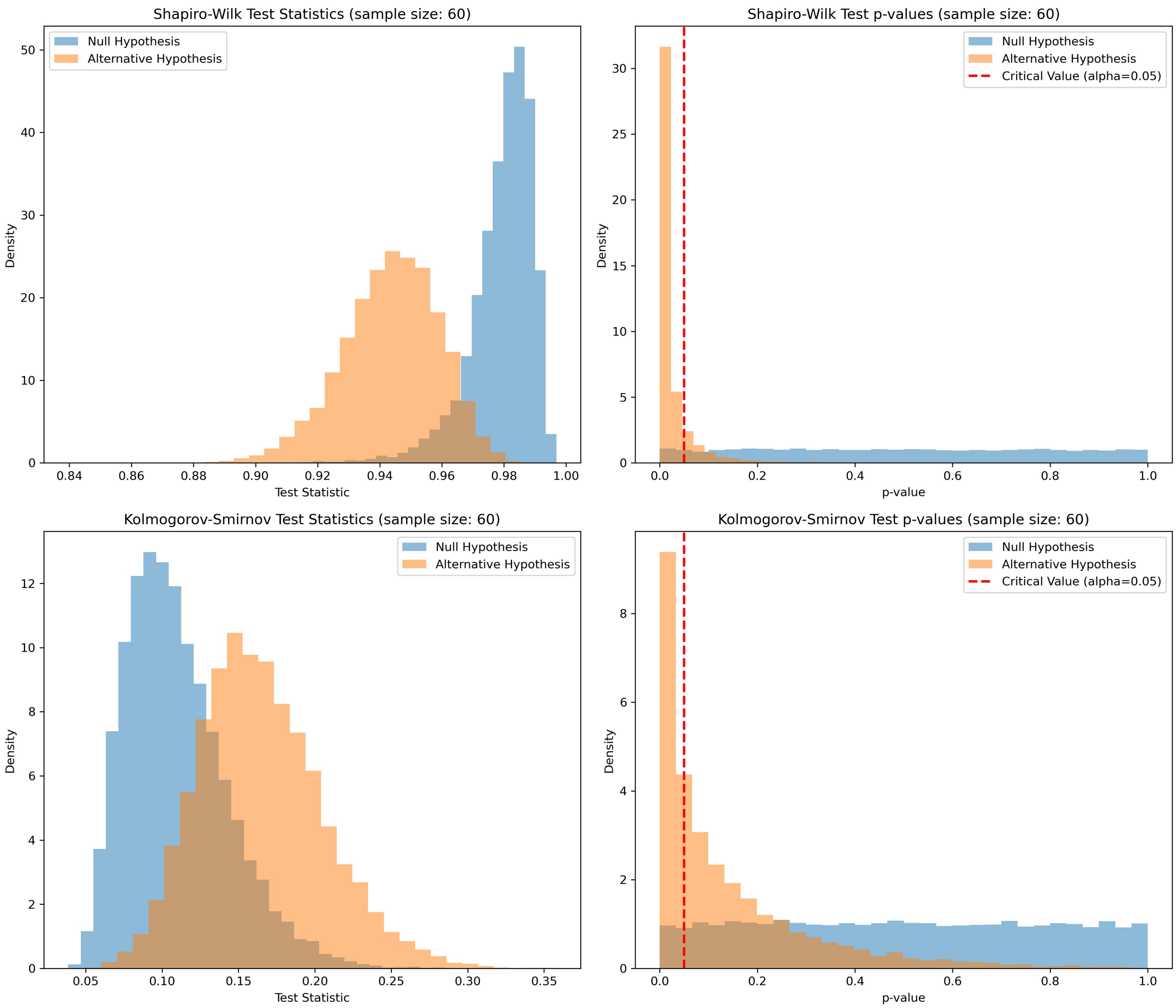


**Figure 2.** Monte Carlo simulation results for normality testing of satellite data during the COVID-19 pandemic.

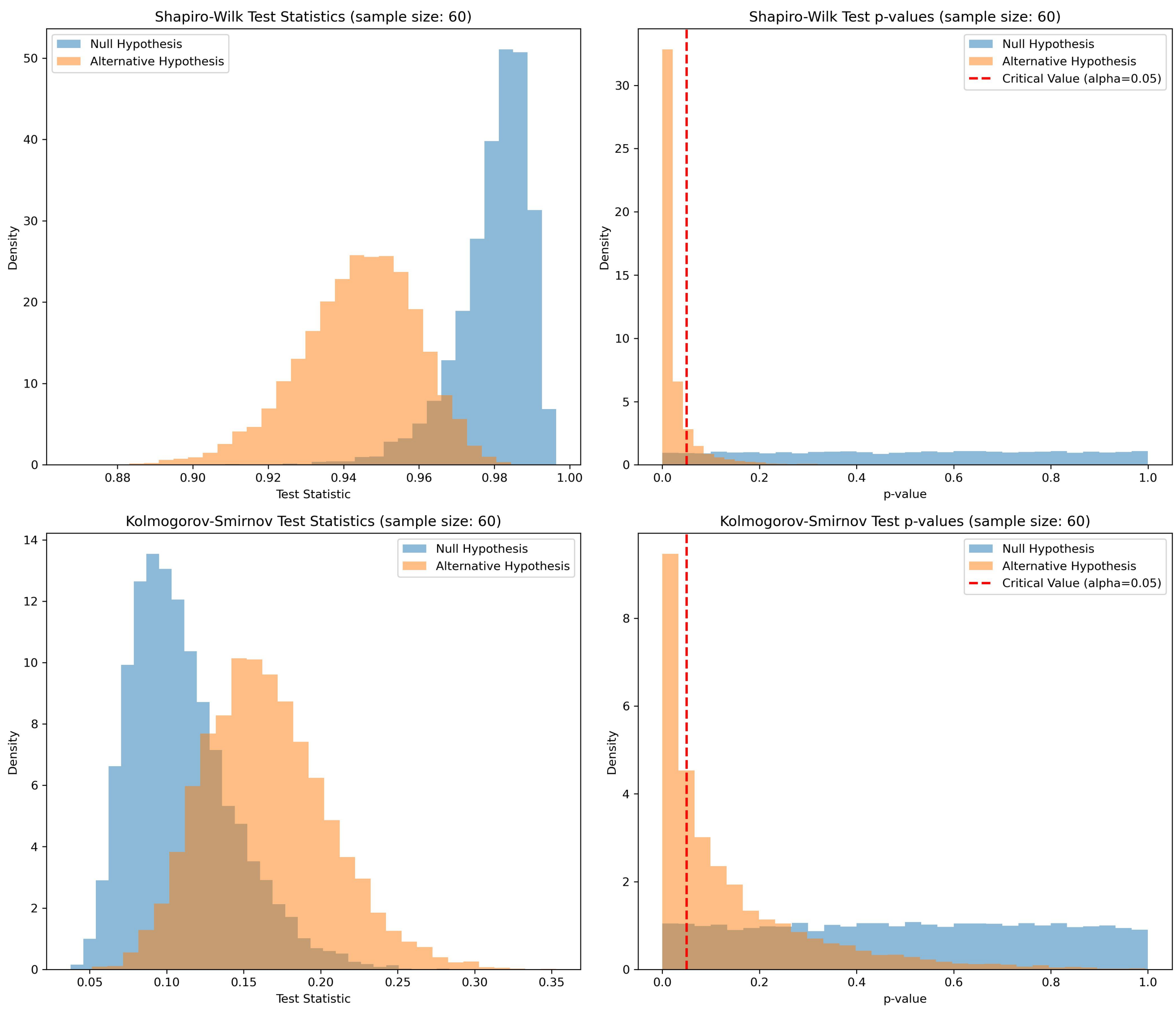


**Figure 3.** Monte Carlo simulation results for normality testing of satellite data after the COVID-19 pandemic.

| Time Range | Test Statistic | Type I Error ($\alpha$) | Type II Error ($\beta$) | Power (1 - $\beta$) | Result |
|---|---|---|---|---|---|
| Before pandemic | S-W | 0.0480 | 0.1332 | 0.8668 | Fail to reject null hypothesis |
| Before pandemic | K-S | 0.0503 | 0.5998 | 0.4002 | Fail to reject null hypothesis |
| During pandemic | S-W | 0.0521 | 0.1349 | 0.8651 | Fail to reject null hypothesis |
| During pandemic | K-S | 0.0481 | 0.6089 | 0.3911 | Fail to reject null hypothesis |
| After pandemic | S-W | 0.0502 | 0.1354 | 0.8646 | Fail to reject null hypothesis |
| After pandemic | K-S | 0.0528 | 0.6063 | 0.3937 | Fail to reject null hypothesis |

**Table 1.** Results of Monte Carlo Simulation for Statistical Test of Before, During, and After Pandemic Data