Group 5

Kumar Vaibhav (P25103)

Shital Gulati (P25117)

Kritesh Sahu (P25102)

Kumari Paki (P25104)

Rishi Soni (P25114)

Analyzing the Impact of Renewable Energy Investments on Economic Growth and Emission Reduction Across Indian States

1. Problem Context Analysis

India has witnessed one of the fastest expansions of renewable energy capacity in the world, driven by ambitious national goals such as achieving **500 GW of non-fossil energy capacity by 2030** and transitioning toward **net-zero emissions by 2070**. Over the past two decades, the rate of adoption of solar photovoltaics, onshore wind, small hydro, biomass-based power, and waste-to-energy systems has increased significantly across states. This rapid expansion is largely supported by national policies, state-level incentives, and an increasing recognition of the need to reduce dependency on fossil fuels.

Despite these advancements, an important strategic and managerial challenge remains unresolved:
Does renewable energy expansion actually translate into meaningful improvements in environmental outcomes and economic growth?

While it is widely assumed that increasing renewable capacity should reduce carbon emissions and stimulate economic activity, the magnitude and consistency of these effects remain uncertain. Several Indian states have aggressively expanded their renewable portfolios, while others have grown more modestly. Yet, emissions continue to rise nationally because of increased electricity demand, continued reliance on coal, and industrial growth. Similarly, economic outcomes may vary depending on state-specific industries, population size, and the maturity of the power sector.

To examine this more rigorously, this study integrates **multi-year panel data (2006–2024)** combining state-wise renewable energy installation data, CO_2 emissions from thermal generation, GSDP, and population. The objective is to empirically test whether states with higher renewable energy growth experience:

1. Lower **emission intensity** (CO_2 per unit GSDP)

2. Higher **GSDP growth**

This aligns with the broader policy idea of **"green growth"**, which suggests that expanding clean energy infrastructure should simultaneously improve sustainability and economic performance.

If renewable energy truly drives economic and environmental gains, it strengthens the case for prioritizing investments in clean energy, grid upgrades, and sectoral reforms. If not, policymakers may need to reassess the complementary measures required to ensure that renewable expansion results in meaningful impact. Thus, this problem is not only academically relevant but also critically important for India's energy policy, climate strategy, and sustainable development pathway.

2. Summary of Data Analysis and Key Findings

2.1 Data Overview and Preparation

The study integrates two major datasets:

1. A **renewable energy dataset** containing state-wise installed capacities for solar, wind, biomass, small hydro, and waste-to-energy from 2006 to 2024, along with population, zone, and GSDP.

2. A **CO_2 emission dataset** derived from thermal power stations, providing state-level emissions aggregated annually.

New variables were constructed to enable analysis:

- **Total Renewable Energy Capacity** (MW)
- **Renewable Energy Growth (%)**
- **GSDP Growth (%)**
- **Emission Intensity** = Total CO_2 / GSDP
- **Technology Mix (% share)**
- **Per-capita Renewable Capacity**

After cleaning, merging, and standardizing state names, the final dataset contained **524 observations** covering almost every major Indian state over 19 years.

2.2 Descriptive Insights

1. Renewable Energy Expansion (2006–2024)

Renewable energy installations increased substantially across the period, primarily due to solar and wind capacity additions. However, the growth rate was highly uneven. Many states experienced years of extremely high growth when new solar or wind parks were commissioned, while others stagnated. Renewable Energy Growth (RE_Growth) ranged from **–100% to over 4100%**, highlighting very volatile adoption patterns.

2. Emission Patterns

CO_2 emissions from thermal power continued to rise across most states due to growing electricity demand and heavy reliance on coal. As a result, **emission intensity** (CO_2/GSDP) varied widely across states and across years, ranging between **0 and 38.39**, with a mean of **3.68**.

3. GSDP Dynamics

State GSDP values increased steadily over time, as expected. However, **GSDP Growth (%)** exhibited high variability, with a range of **–15.38% to nearly 400%** in some smaller states/union territories.

2.3 Correlation Analysis

Correlation results revealed:

- **Total_RE and GSDP → +0.50**
- **Total_RE and CO_2 → +0.75**
- **GSDP and CO_2 → +0.76**
- **RE_Growth and GSDP_Growth → –0.04**
- **RE_Growth and Emission_Intensity → –0.06**

These correlations point to three important patterns:

1. Economic growth and CO_2 emissions rise together, reflecting industrial and energy demand expansion.
2. States with more renewable energy capacity also tend to have more emissions and higher GDP—likely driven by overall energy demand rather than renewable penetration.
3. Year-wise renewable energy growth does **not** correlate well with economic or environmental outcomes.

2.4 Regression Analysis Findings

Model 1: RE_Growth → Emission_Intensity

- **R^2 = 0.002**, insignificant
- Renewable energy growth does **not** meaningfully reduce emission intensity.

Model 2: RE_Growth → GSDP_Growth

- **R^2 = 0.001**, insignificant
- Renewable growth does **not** increase economic growth on a year-to-year basis.

Model 3: Total_RE → Emission_Intensity

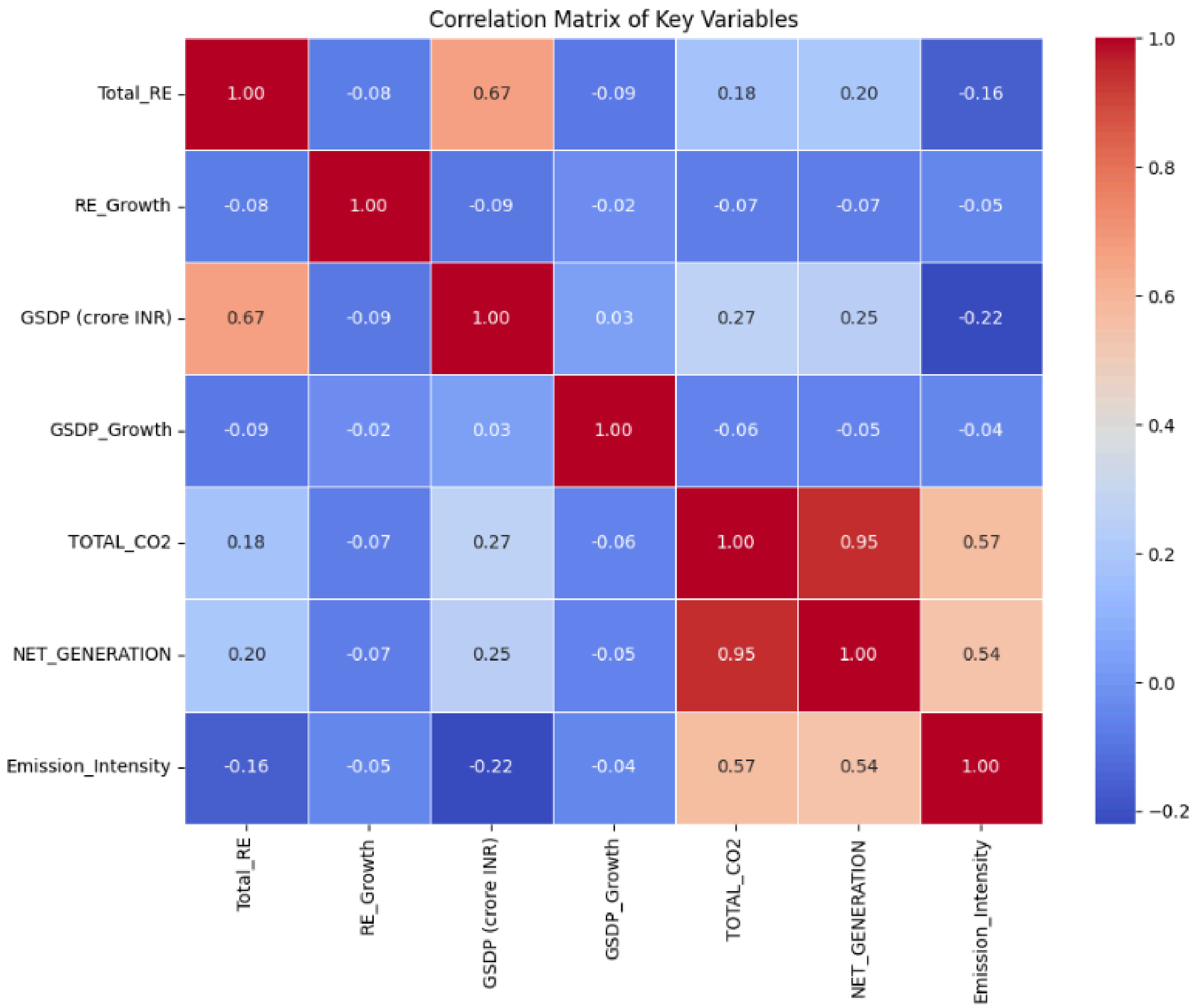
- **R^2 = 0.026**, coefficient slightly negative and significant
- States with **higher absolute renewable capacity** tend to have slightly lower emission intensity.
- However, effect size is very small.

Model 4: Total_RE + GSDP → Emission_Intensity

- **R^2 = 0.048**, GSDP is significant
- Once economic size is controlled for, renewable capacity becomes **insignificant**.
- This indicates that **economic development**, not renewable energy, is the primary driver of lower emission intensity.

Model 5: Total_RE → GSDP_Growth

- **R^2 = 0.007**, marginal insignificance
- Renewable expansion does not meaningfully explain GSDP growth.



2.5 Interpretation of Analytical Findings

The combined findings indicate that renewable energy expansion has **not** yet evolved into a strong driver of green growth at the state level in India.
The key interpretations include:

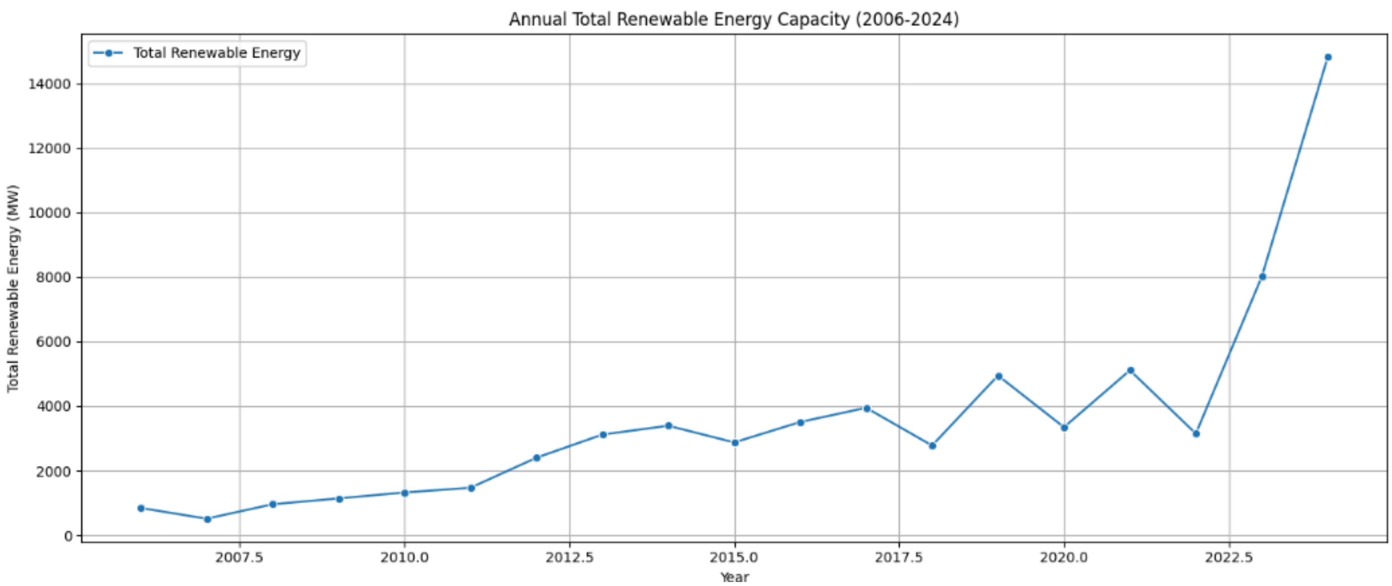
1. **Renewables alone do not reduce emissions** in a significant linear manner. Emission reductions are more strongly associated with larger GSDP values, which may indicate greater efficiency, better infrastructure, or more advanced industrial structures.

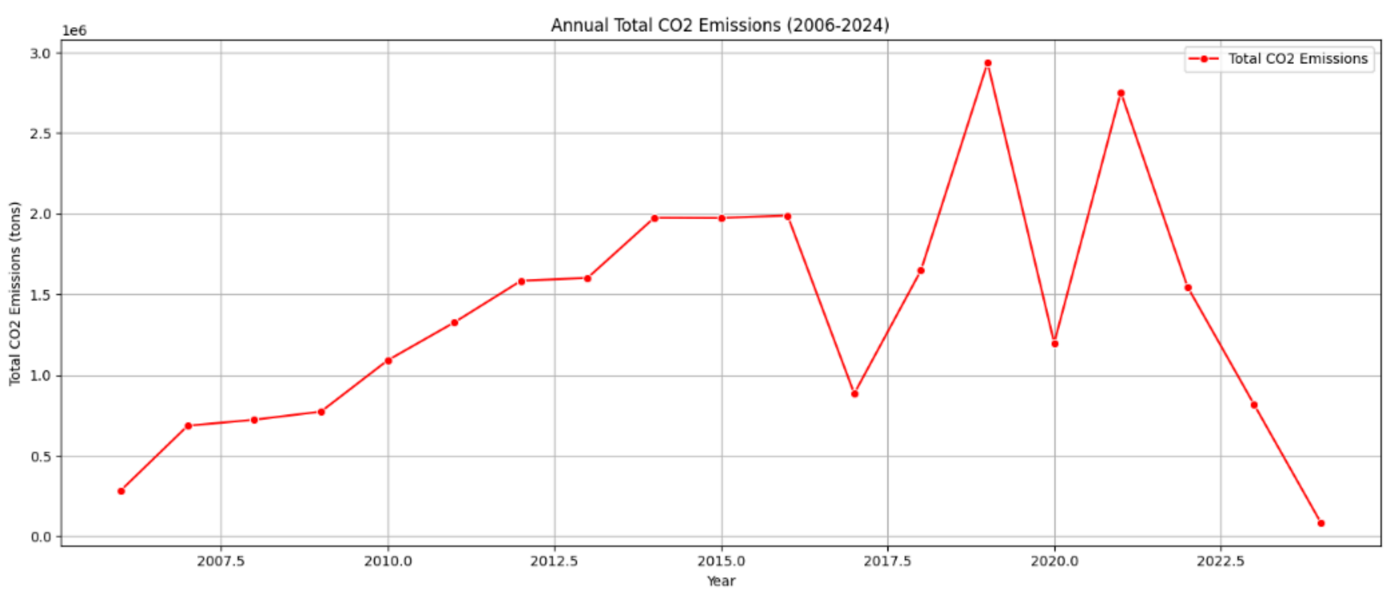
2. **Renewables do not directly increase economic output** in measurable short-term increments. This aligns with existing policy literature that suggests renewable energy serves more as a long-term infrastructure investment rather than a near-term economic stimulus.

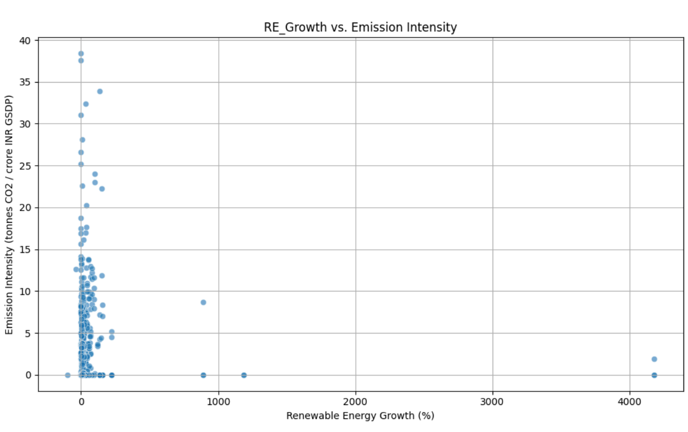
3. **India's energy system remains dominated by coal**, meaning that renewable additions are not yet displacing fossil fuels at the scale required to visibly affect emissions.

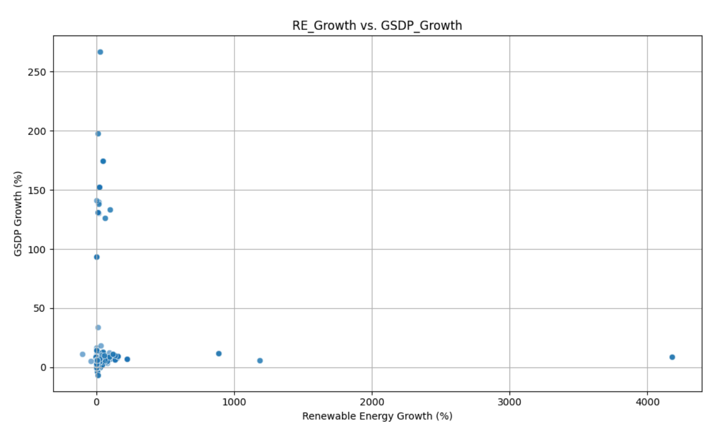
4. **Volatility in renewable installation patterns** implies that year-to-year growth does not translate into smooth or predictable outcomes.

5. **Emission and GDP patterns appear driven by structural economic factors**, not annual renewable growth metrics.









3. Recommendations

1. Integrate Renewable Energy Expansion with Broader Economic and Industrial Reforms

Renewable energy capacity alone does not strongly influence emission intensity or GDP growth. States must pair RE development with cleaner industrial processes, improved energy efficiency, and electrification of transport sectors.

2. Prioritize Renewable Energy as a Long-Term Sustainability Investment, Not a Short-Term GDP Driver

Since RE has limited short-term economic impact, policymakers should emphasize climate mitigation, energy security, and resilience rather than immediate financial returns.

3. Accelerate Grid Modernization and Storage Infrastructure

The benefits of renewable energy will only materialize when grid flexibility, transmission capacity, and storage systems support large-scale integration.

4. Promote Sectoral Decarbonization to Amplify RE Impact

Heavy industries, transport, and manufacturing must adopt low-carbon pathways. Only then will renewable energy significantly reduce emissions.

5. Study Non-Linear, Lagged, and Threshold Effects in Future Research

Renewable benefits may emerge only after crossing certain penetration levels or after multi-year lags. States with mature RE ecosystems may begin to show stronger environmental and economic effects over time.

Appendix:

Github Link for dataset and Analysis:
https://github.com/kayvaibhav/Green-Growth-Analysis

```
Regression Model 1: RE_Growth vs. Emission_Intensity
                            OLS Regression Results
==============================================================================
Dep. Variable:     Emission_Intensity   R-squared:                       0.002
Model:                            OLS   Adj. R-squared:                  0.000
Method:                 Least Squares   F-statistic:                     1.079
Date:                Mon, 17 Nov 2025   Prob (F-statistic):              0.299
Time:                        11:35:56   Log-Likelihood:                -1563.6
No. Observations:                 498   AIC:                             3131.
Df Residuals:                     496   BIC:                             3140.
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      3.8126      0.255     14.942      0.000       3.311       4.314
RE_Growth     -0.0008      0.001     -1.039      0.299      -0.002       0.001
==============================================================================
Omnibus:                      326.540   Durbin-Watson:                   0.833
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             3048.762
Skew:                           2.837   Prob(JB):                         0.00
Kurtosis:                      13.712   Cond. No.                         349.
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.

Regression Model 2: RE_Growth vs. GSDP_Growth
                            OLS Regression Results
==============================================================================
Dep. Variable:            GSDP_Growth   R-squared:                       0.001
Model:                            OLS   Adj. R-squared:                 -0.001
Method:                 Least Squares   F-statistic:                    0.2581
Date:                Mon, 17 Nov 2025   Prob (F-statistic):              0.612
Time:                        11:35:56   Log-Likelihood:                -2527.2
No. Observations:                 498   AIC:                             5058.
Df Residuals:                     496   BIC:                             5067.
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept     17.6889      1.766     10.015      0.000      14.219      21.159
```

```
RE_Growth     -0.0026      0.005     -0.508      0.612      -0.013       0.007
==============================================================================
Omnibus:                      401.378   Durbin-Watson:                   0.744
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             4860.606
Skew:                           3.680   Prob(JB):                         0.00
Kurtosis:                      16.419   Cond. No.                         349.
==============================================================================
```

Regression Model 3: Simple Linear Regression of Emission_Intensity vs. Total_RE

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     Emission_Intensity   R-squared:                       0.026
Model:                            OLS   Adj. R-squared:                  0.024
Method:                 Least Squares   F-statistic:                     14.12
Date:                Mon, 17 Nov 2025   Prob (F-statistic):           0.000191
Time:                        11:40:55   Log-Likelihood:                -1647.6
No. Observations:                 524   AIC:                             3299.
Df Residuals:                     522   BIC:                             3308.
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept      4.3298      0.301     14.403      0.000       3.739       4.920
Total_RE      -0.0002   6.51e-05     -3.757      0.000      -0.000      -0.000
==============================================================================
Omnibus:                      342.028   Durbin-Watson:                   0.951
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             3309.377
Skew:                           2.817   Prob(JB):                         0.00
Kurtosis:                      13.946   Cond. No.                     5.64e+03
==============================================================================
```

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 5.64e+03. This might indicate that there are strong multicollinearity or other numerical problems.

Regression Model 4: Multiple Linear Regression of Emission_Intensity vs. Total_RE and GSDP (crore INR)

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     Emission_Intensity   R-squared:                       0.048
Model:                            OLS   Adj. R-squared:                  0.045
Method:                 Least Squares   F-statistic:                     13.26
Date:                Mon, 17 Nov 2025   Prob (F-statistic):           2.42e-06
Time:                        11:40:55   Log-Likelihood:                -1641.6
No. Observations:                 524   AIC:                             3289.
```

```
Df Residuals:                     521   BIC:                             3302.
Df Model:                           2
Covariance Type:            nonrobust
=========================================================================================
===
                              coef    std err          t      P>|t|      [0.025
0.975]
-----------------------------------------------------------------------------------------
---
Intercept                   5.1466      0.379     13.581      0.000       4.402
5.891
Total_RE                -4.272e-05   8.68e-05     -0.492      0.623      -0.000
0.000
Q("GSDP (crore INR)") -2.565e-06   7.37e-07     -3.479      0.001   -4.01e-06
-1.12e-06
==============================================================================
Omnibus:                      326.281   Durbin-Watson:                   0.970
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             2978.599
Skew:                           2.665   Prob(JB):                         0.00
Kurtosis:                      13.393   Cond. No.                     1.07e+06
==============================================================================

Regression Model 5: Simple Linear Regression of GSDP_Growth vs. Total_RE
                            OLS Regression Results
==============================================================================
Dep. Variable:            GSDP_Growth   R-squared:                       0.007
Model:                            OLS   Adj. R-squared:                  0.005
Method:                 Least Squares   F-statistic:                     3.673
Date:                Mon, 17 Nov 2025   Prob (F-statistic):             0.0559
Time:                        11:41:13   Log-Likelihood:                -2525.5
No. Observations:                 498   AIC:                             5055.
Df Residuals:                     496   BIC:                             5063.
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
Intercept     19.9084      2.131      9.342      0.000      15.721      24.096
Total_RE      -0.0009      0.000     -1.916      0.056      -0.002    2.18e-05
==============================================================================
Omnibus:                      399.137   Durbin-Watson:                   0.748
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             4780.078
Skew:                           3.655   Prob(JB):                         0.00
Kurtosis:                      16.301   Cond. No.                     5.81e+03
==============================================================================
```