Project Report: Investigating Renewable Energy's Impact on CO_2 and GHG Emissions

Prepared for Stakeholders

Date: August 21, 2025

Author: Chiagoziem Cyriacus Ugoh

Purpose: This report investigates whether increased renewable energy usage correlates with reductions in CO_2 and GHG emissions per capita, identifying trends, regional disparities, and standout countries. It addresses four key questions, provides detailed visualization explanations, actionable insights, and recommendations. All insights derive from the dataset (2,405 rows, 79 countries, 1992–2023, 6 regions: Africa, Asia, Europe, North America, South America, Australia).

Executive Summary

The analysis reveals that renewable energy adoption correlates strongly with reduced CO_2 and GHG emissions in developed regions (Europe: -0.949, North America: -0.816), but not in developing ones (Asia: 0.336, Africa: 0.352), where emissions rise with renewables due to economic growth. Global CO_2 doubled from ~20,887 Mt (1992) to ~35,495 Mt (2023), with renewables tripling but showing a positive global correlation (0.831). Per capita CO_2 is lower in high-renewables regions (~6–7 t/person in Europe vs. global ~8 t). Forecasts suggest stabilization (~35,000 Mt by 2028), with Europe declining further and Asia/Africa rising without intervention. Standout countries include China (highest CO_2), Germany (renewables leader), and Algeria (volatile renewables).

Actionable Insights:

- Strong negative correlations in Europe/North America show renewables displace fossils; positive correlations elsewhere indicate scaling needs.
- Top emitters (China, US) contribute ~40% of CO_2; focus here maximizes impact.

- Per capita disparities: High-renewables countries (e.g., Nordics) ~5–7 t vs. low (e.g., Qatar) ~20+ t.

Recommendations:

- Allocate 25% of ESG budgets to renewables in Asia/Africa to achieve decoupling.
- Adopt EU-style policies (e.g., subsidies) globally; prioritize top emitters.
- Deploy notebook's Streamlit dashboard for real-time monitoring; update forecasts yearly.

1. Introduction and Project Goal

Goal: Investigate if renewable energy usage reduces CO_2 and GHG emissions per capita, while identifying trends, regional disparities, and standout countries.
Key Questions:

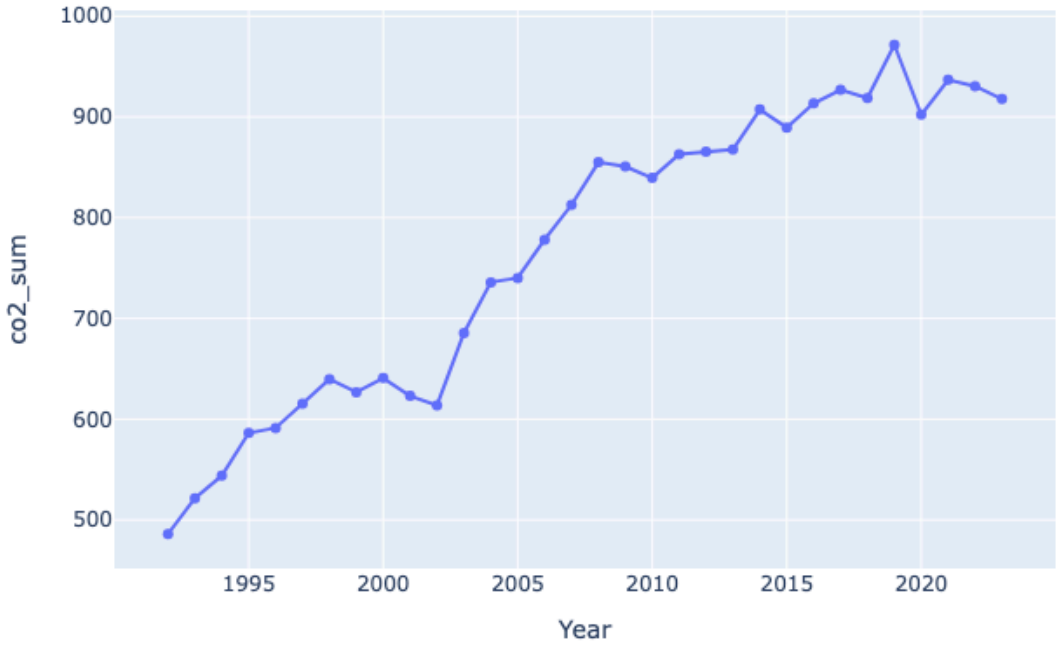
1. Does renewable energy adoption lead to lower CO_2 emissions?
2. Which regions/countries are leading or lagging in renewables?
3. What are the patterns, anomalies, or turning points in the data?
4. How do per capita emissions differ between high- and low-renewables countries?

Why This Matters: With global CO_2 doubling since 1992, understanding renewables' impact guides policy, investment, and corporate ESG strategies for net-zero targets.

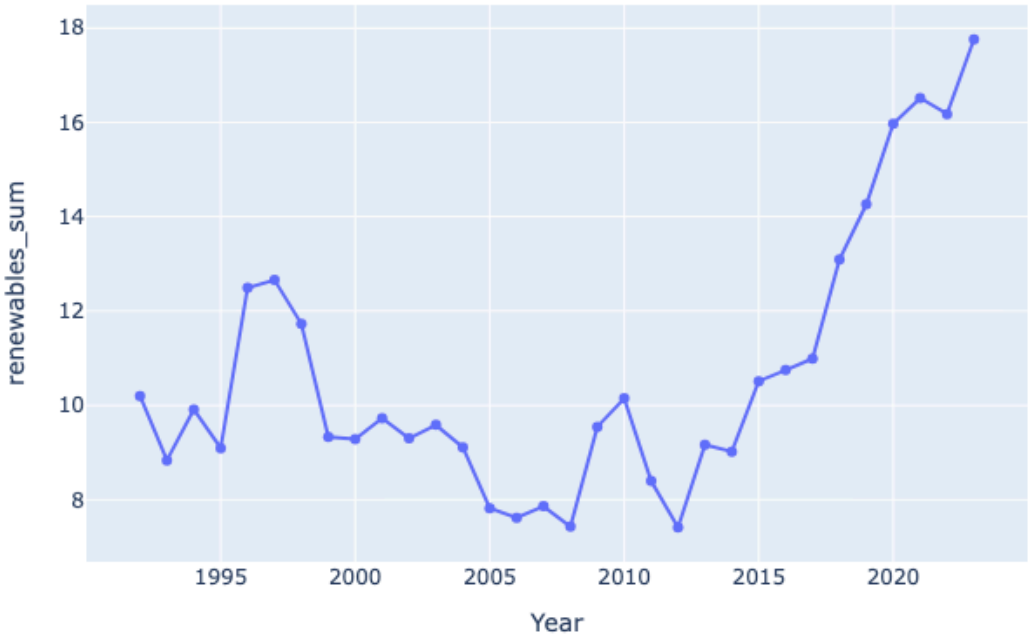
Data Overview: The dataset includes 2,405 cleaned rows (from 2,686), covering 79 countries, with metrics like CO_2 (Mt), GHG (Mt CO_2eq), renewables (equivalent primary energy units), and CO_2 per capita (t/person). Analysis uses pandas, SQL, Plotly, and SARIMAX for forecasting.

2. Detailed Analysis and Visualizations

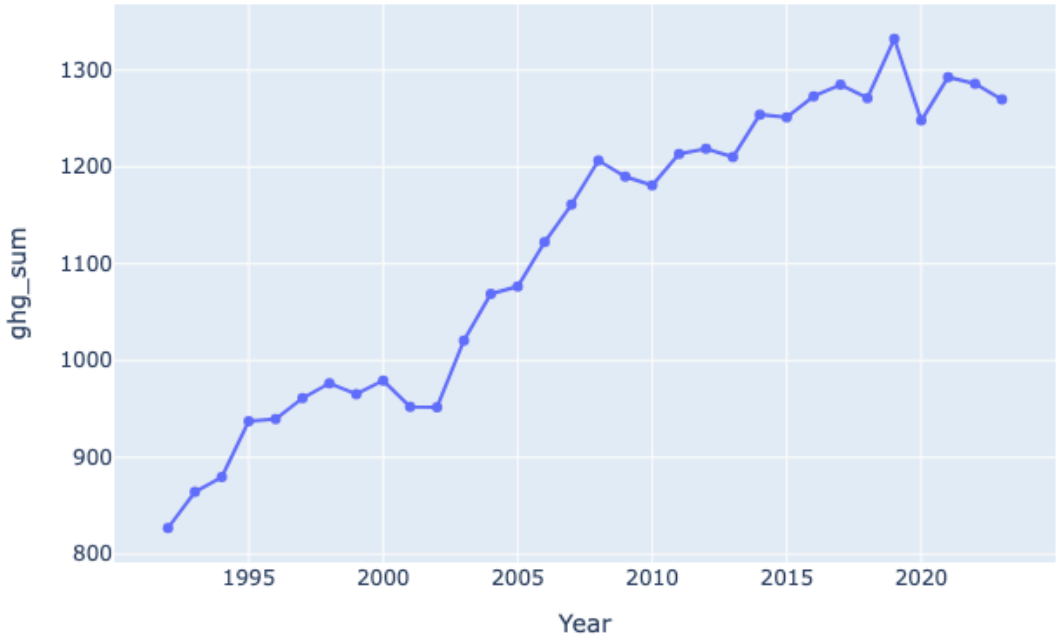
Africa — CO_2 over time



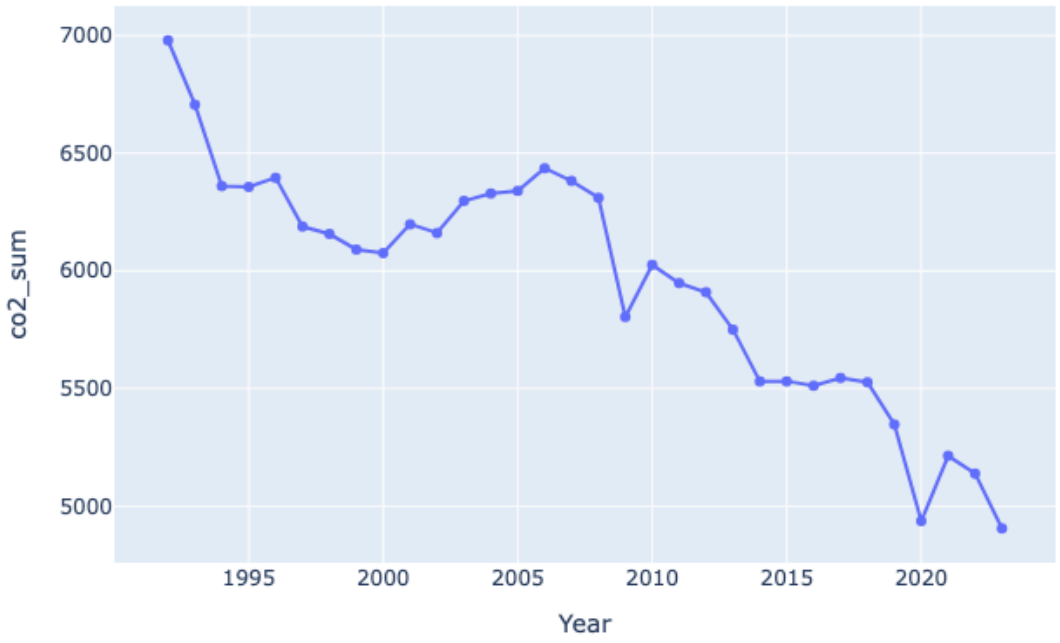
Africa — Renewables over time



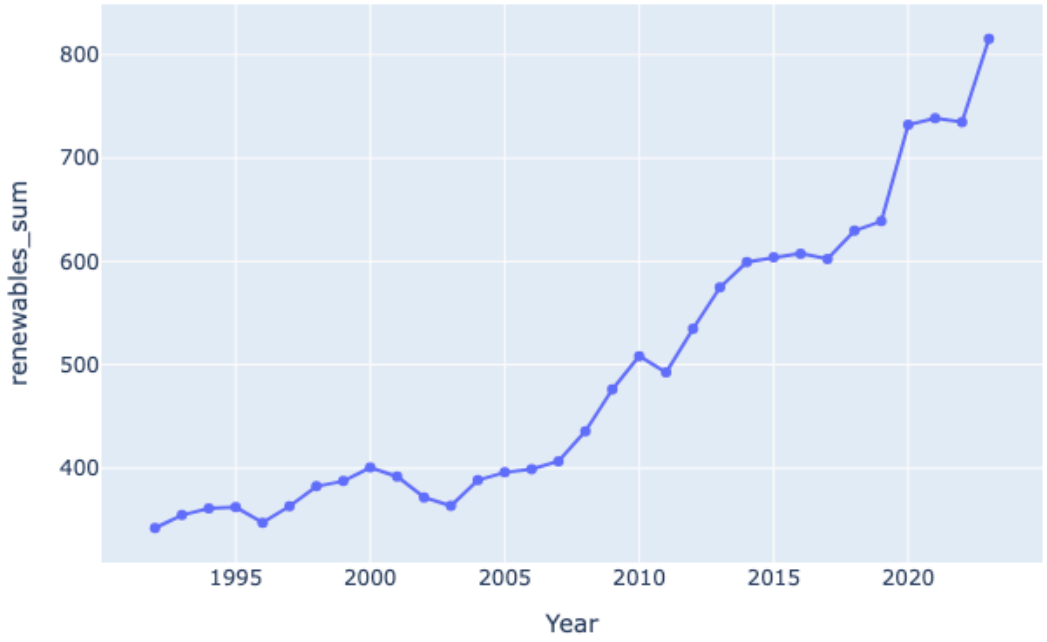
Africa — GHG over time



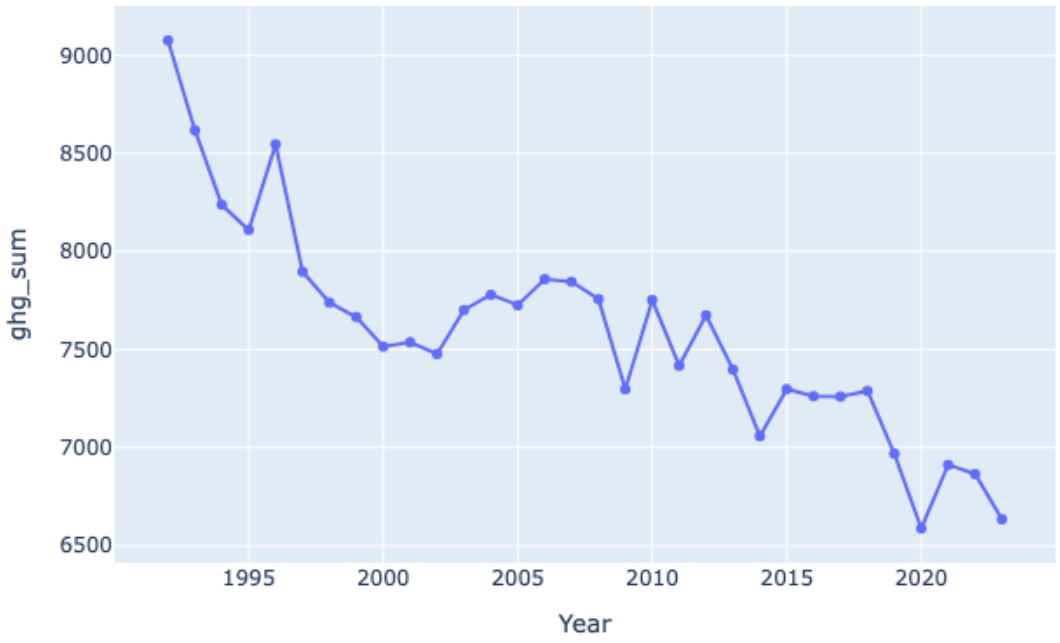
Europe — CO_2 over time



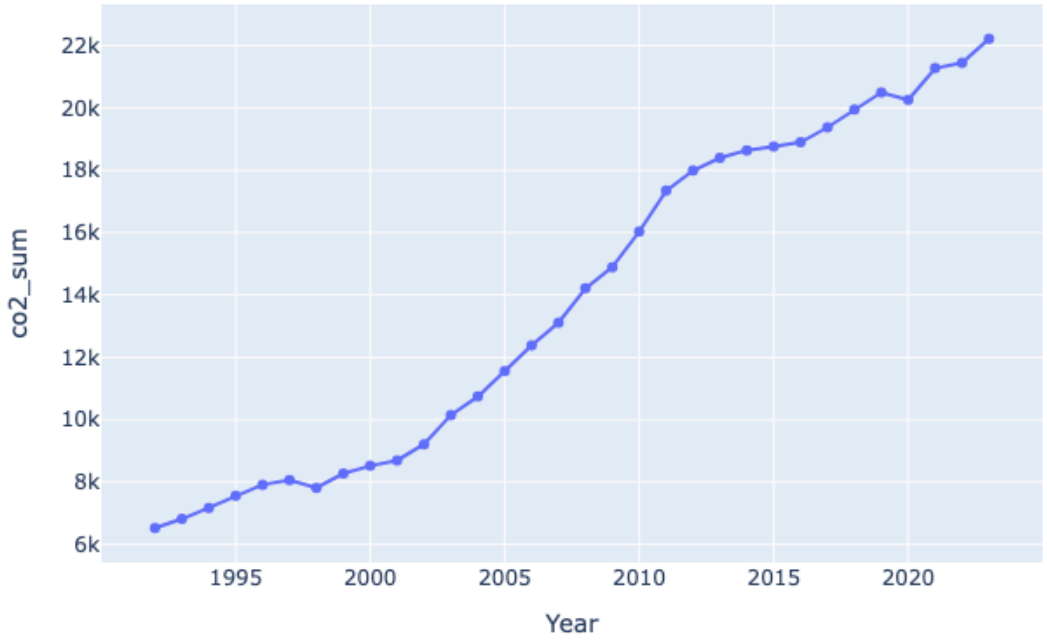
Europe — Renewables over time



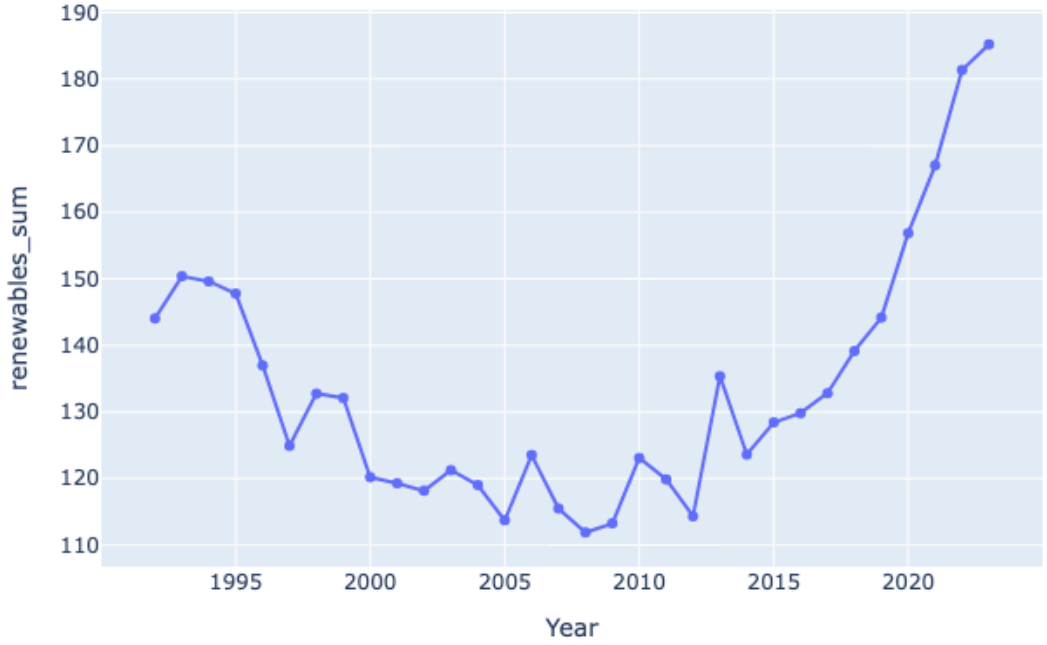
Europe — GHG over time



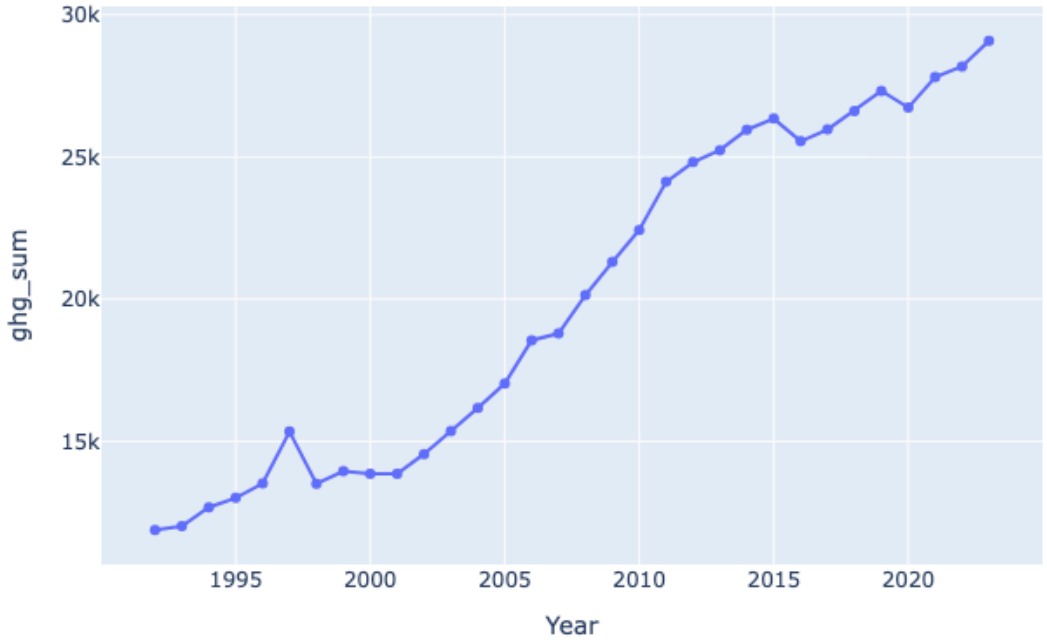
Asia — CO_2 over time



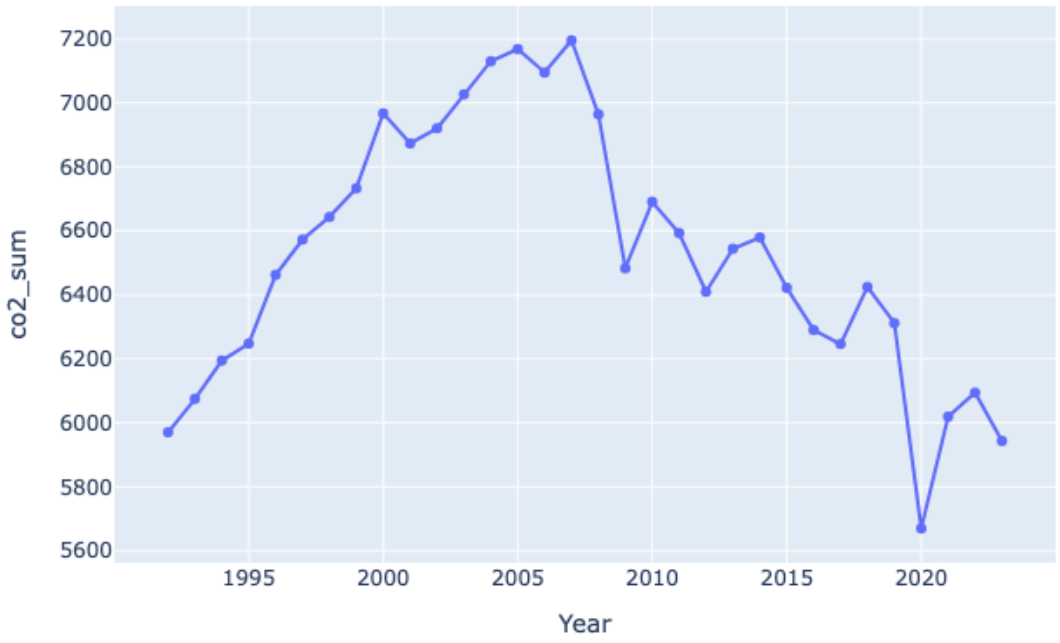
Asia — Renewables over time



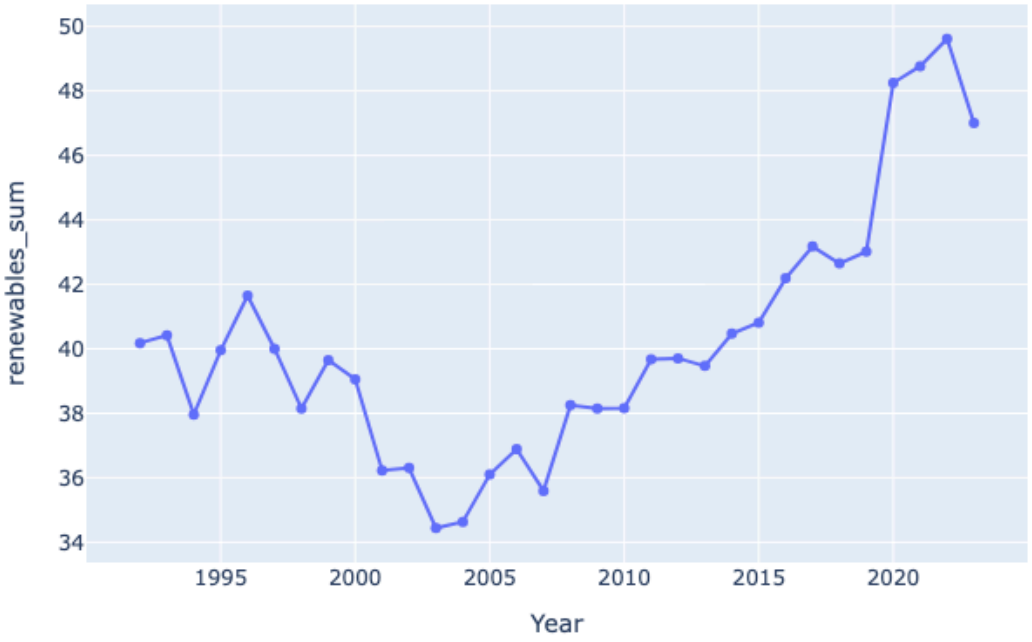
Asia — GHG over time



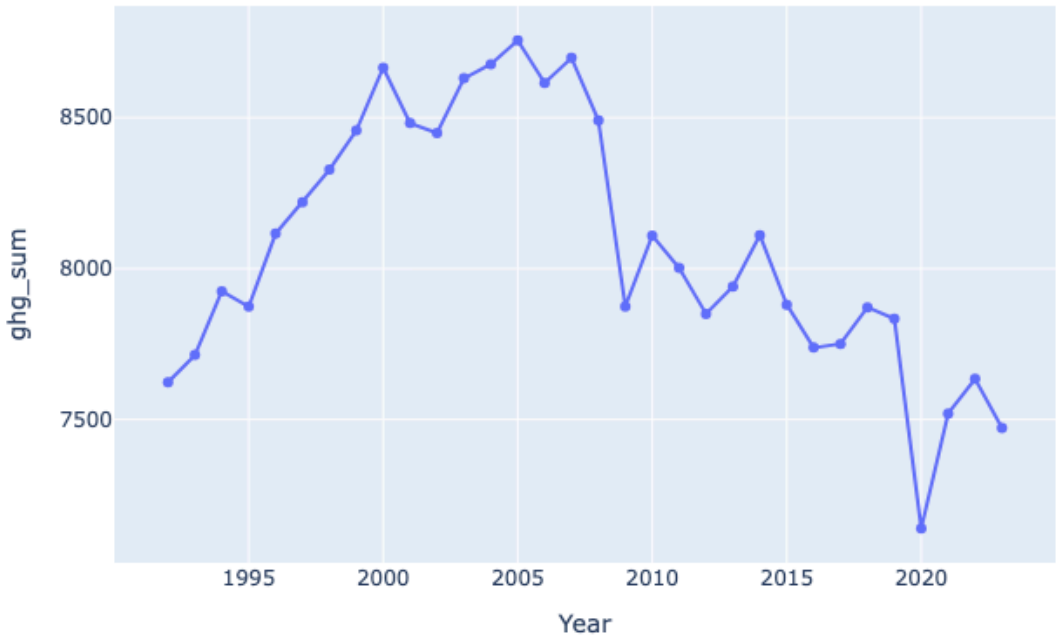
North America — CO_2 over time



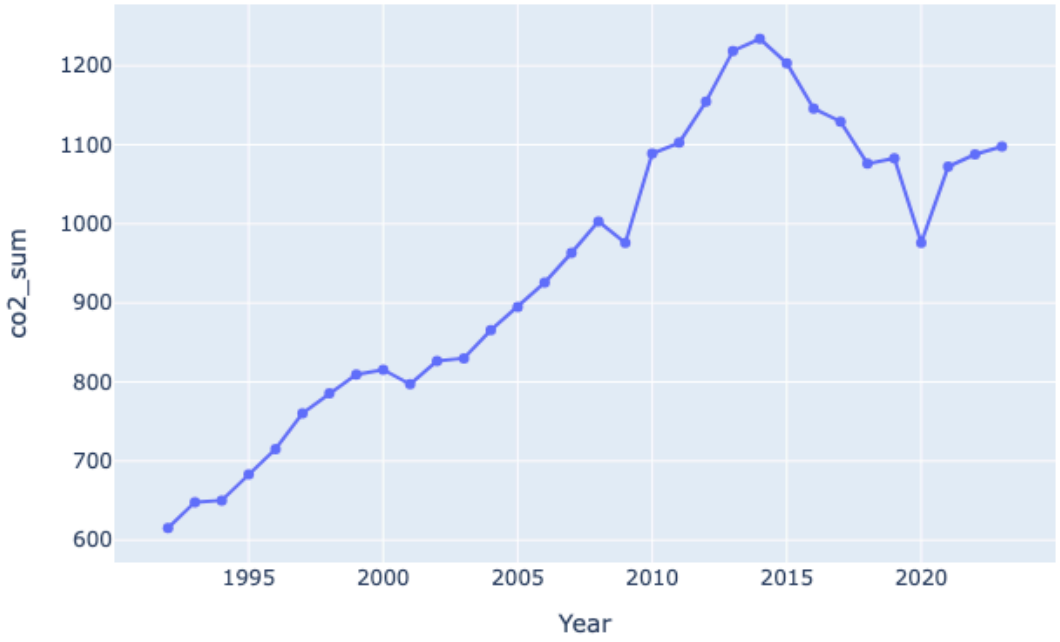
North America — Renewables over time



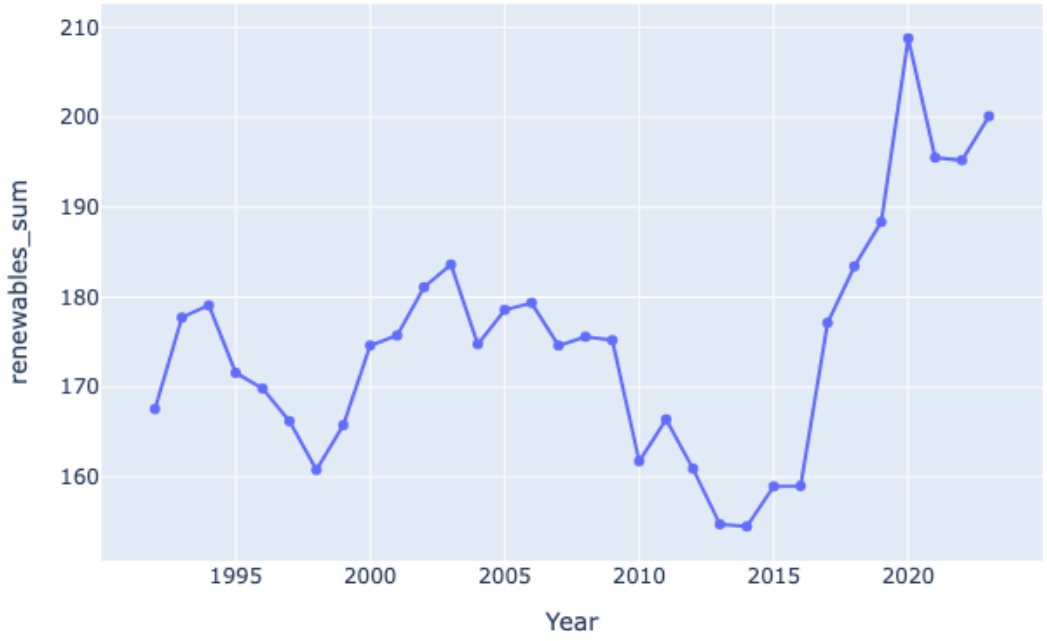
North America — GHG over time



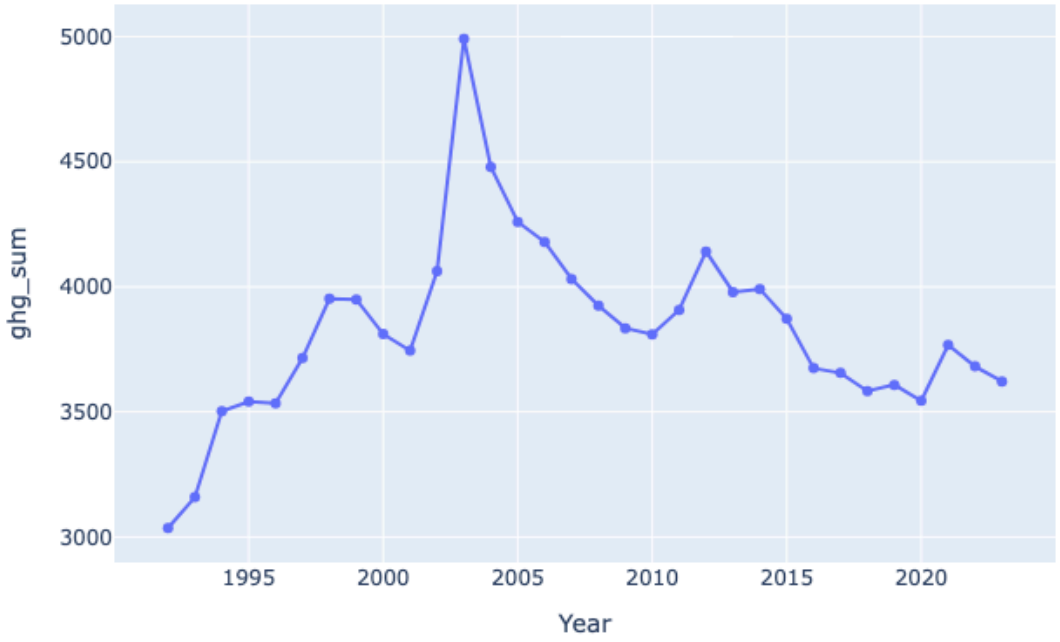
South America — CO_2 over time



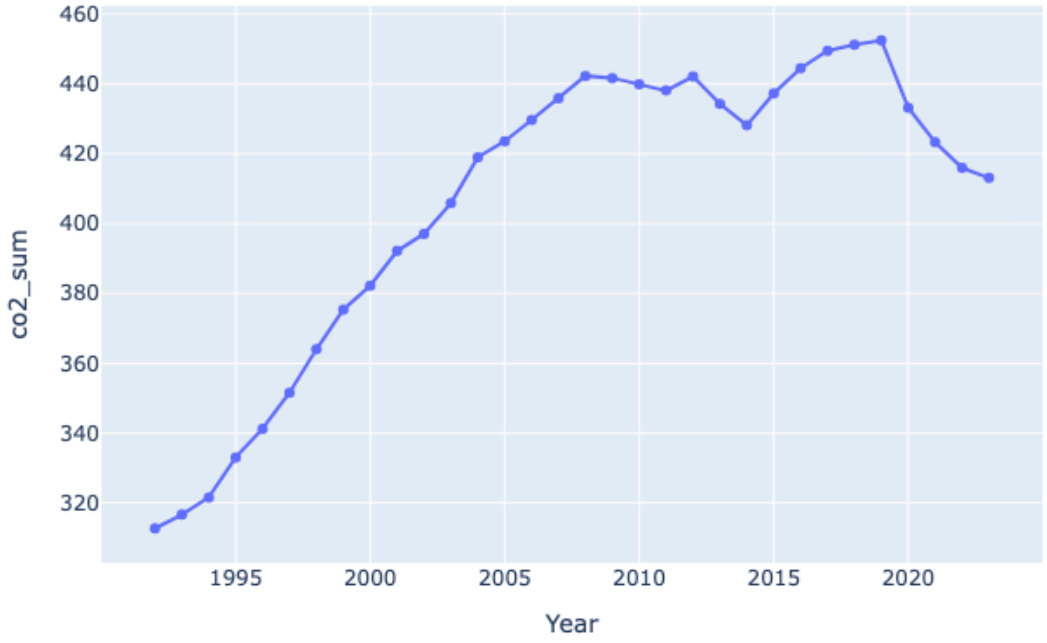
South America — Renewables over time



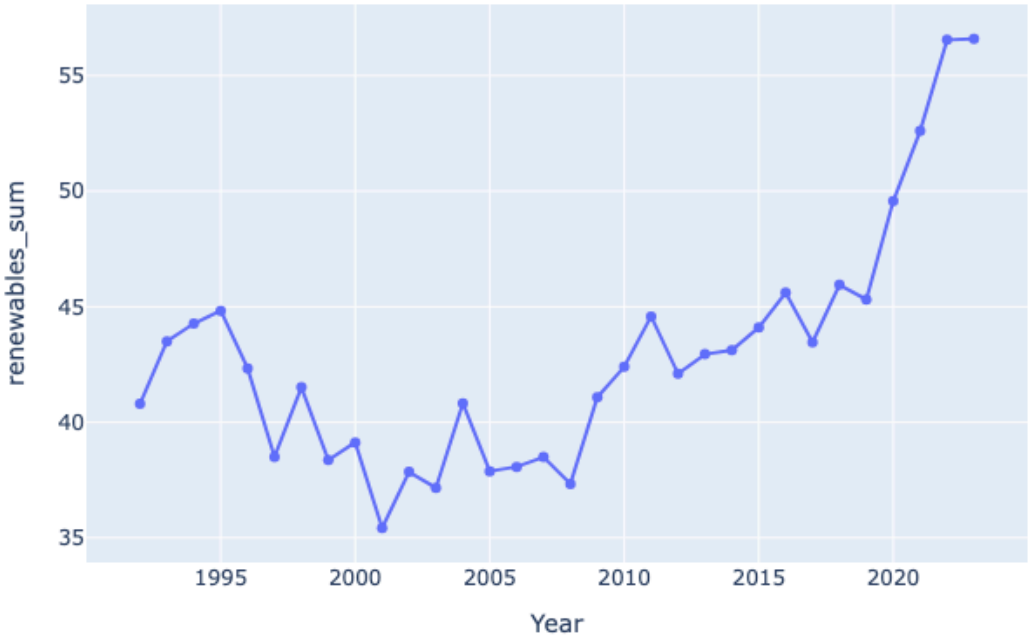
South America — GHG over time



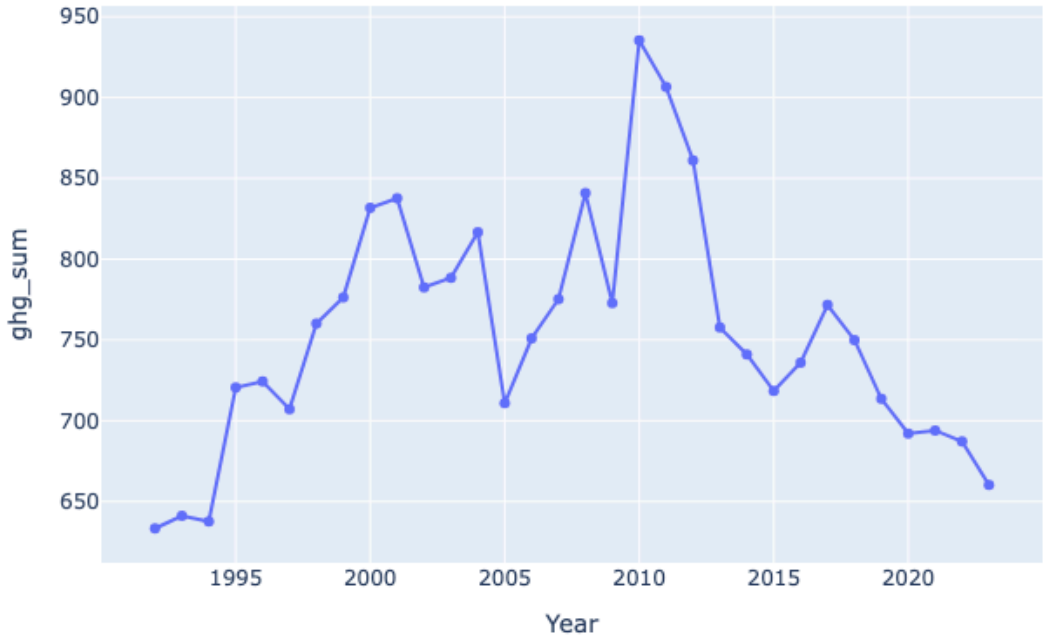
Australia — CO_2 over time



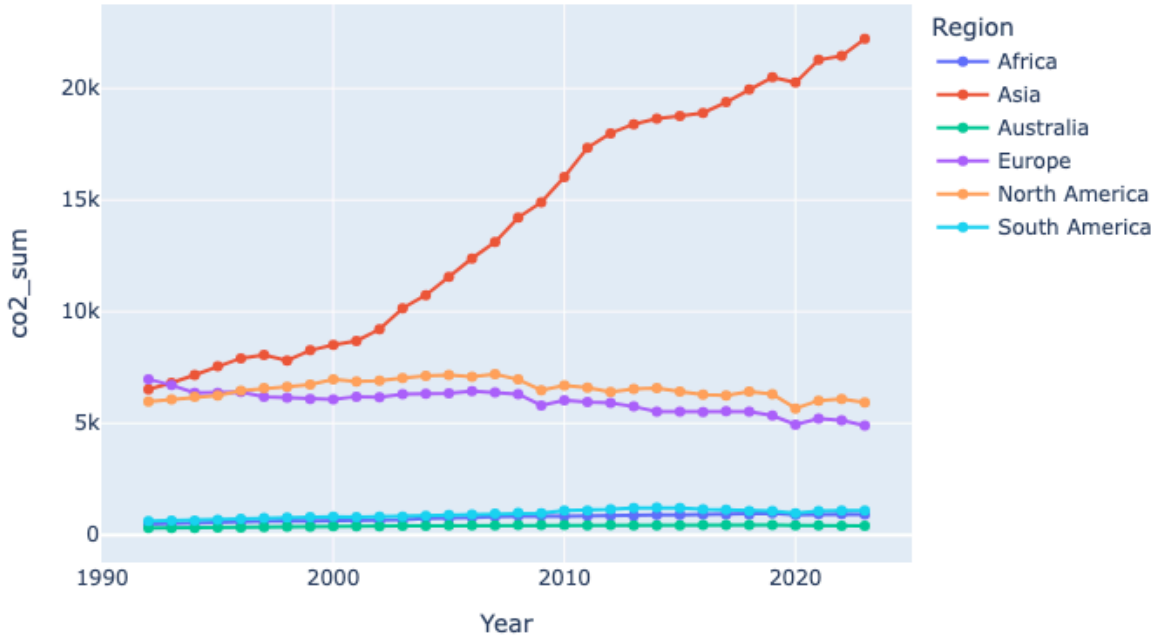
Australia — Renewables over time



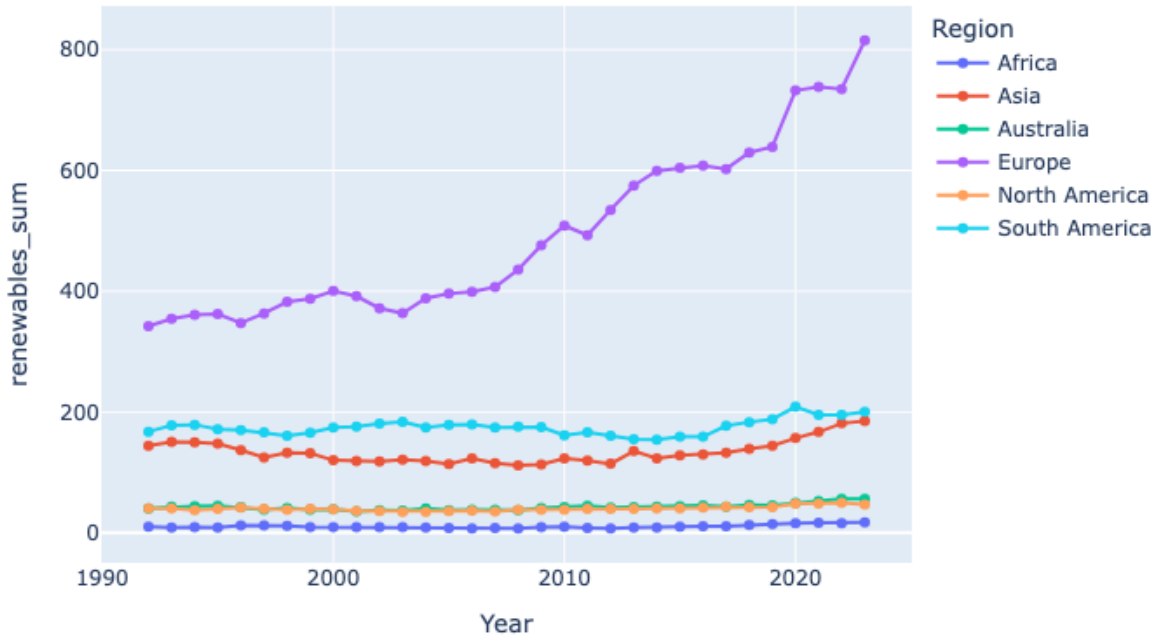
Australia — GHG over time

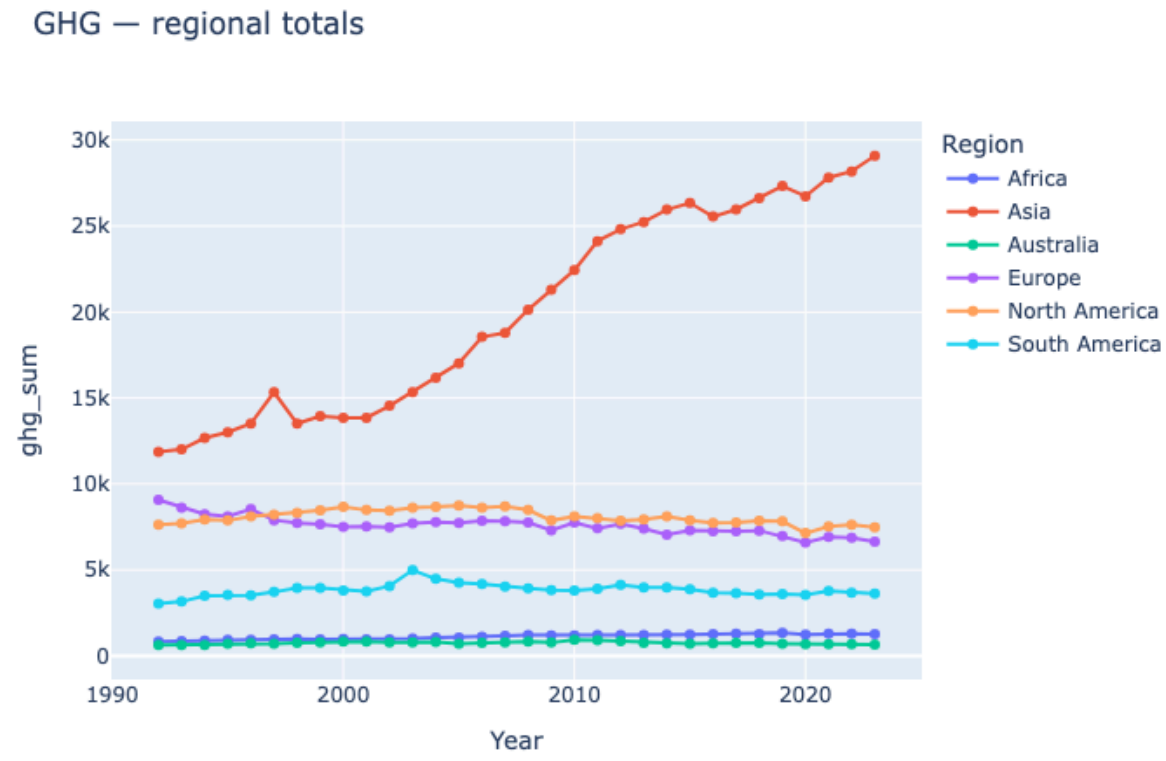


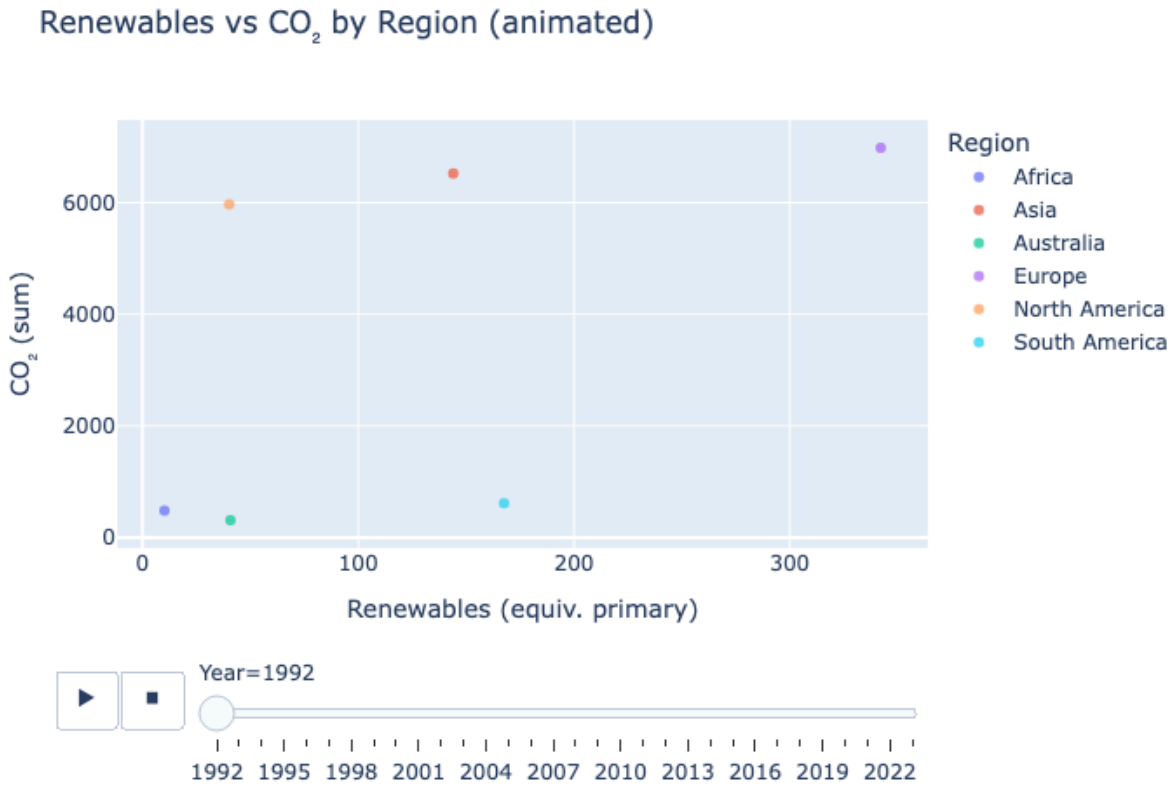
CO_2 — regional totals



Renewables — regional totals

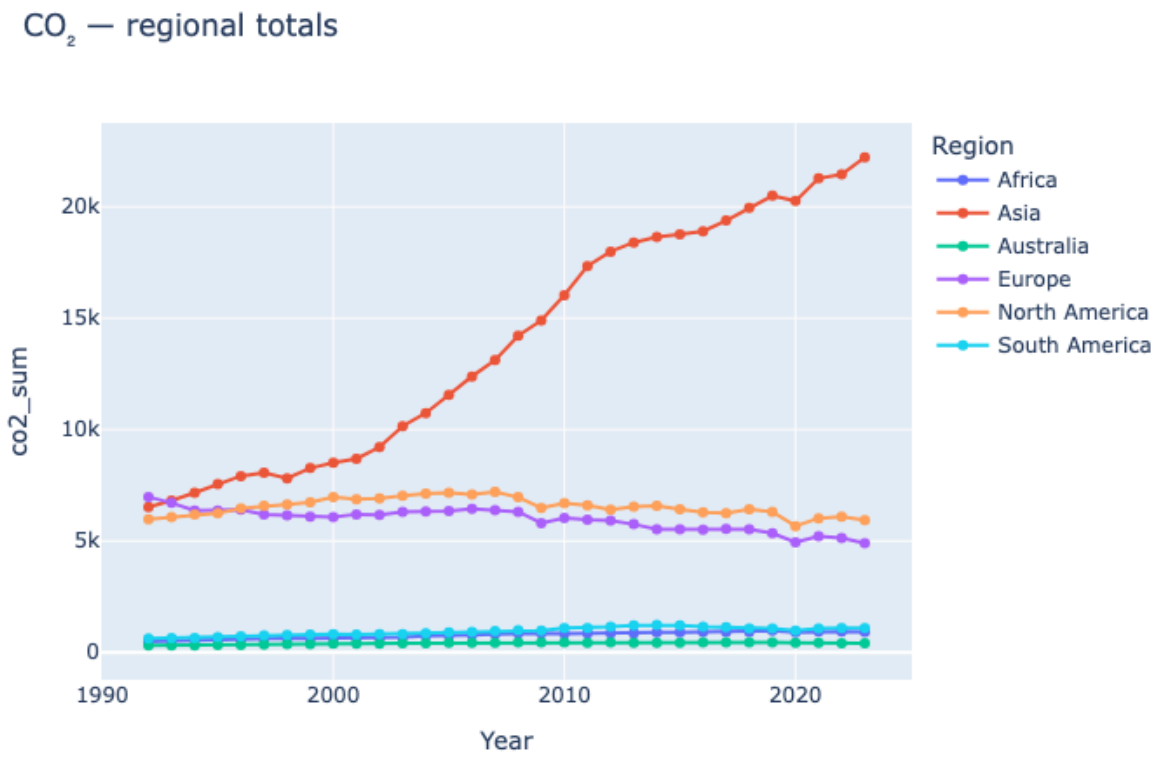






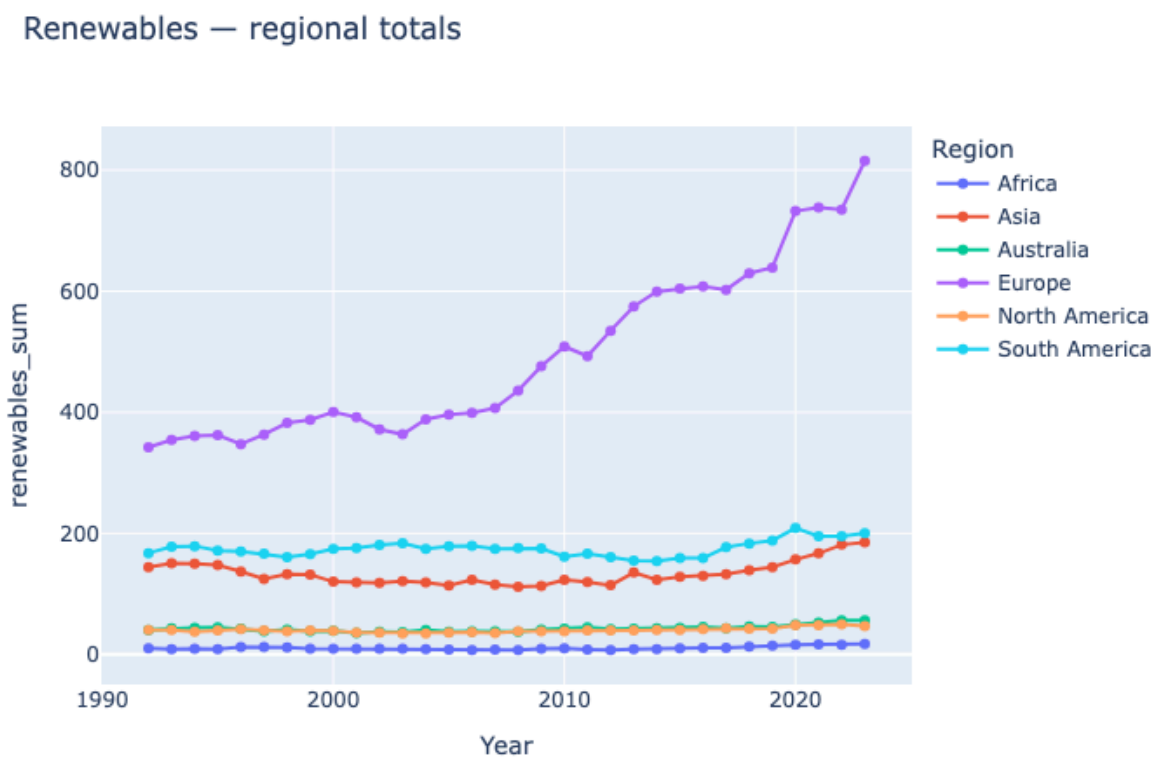
2.1 Does Renewable Energy Adoption Lead to Lower CO_2 Emissions?

Answer: Yes in developed regions (Europe, North America), where strong negative correlations indicate renewables displace fossils. In developing regions (Asia, Africa), positive correlations suggest renewables add capacity without reducing emissions, driven by growth.



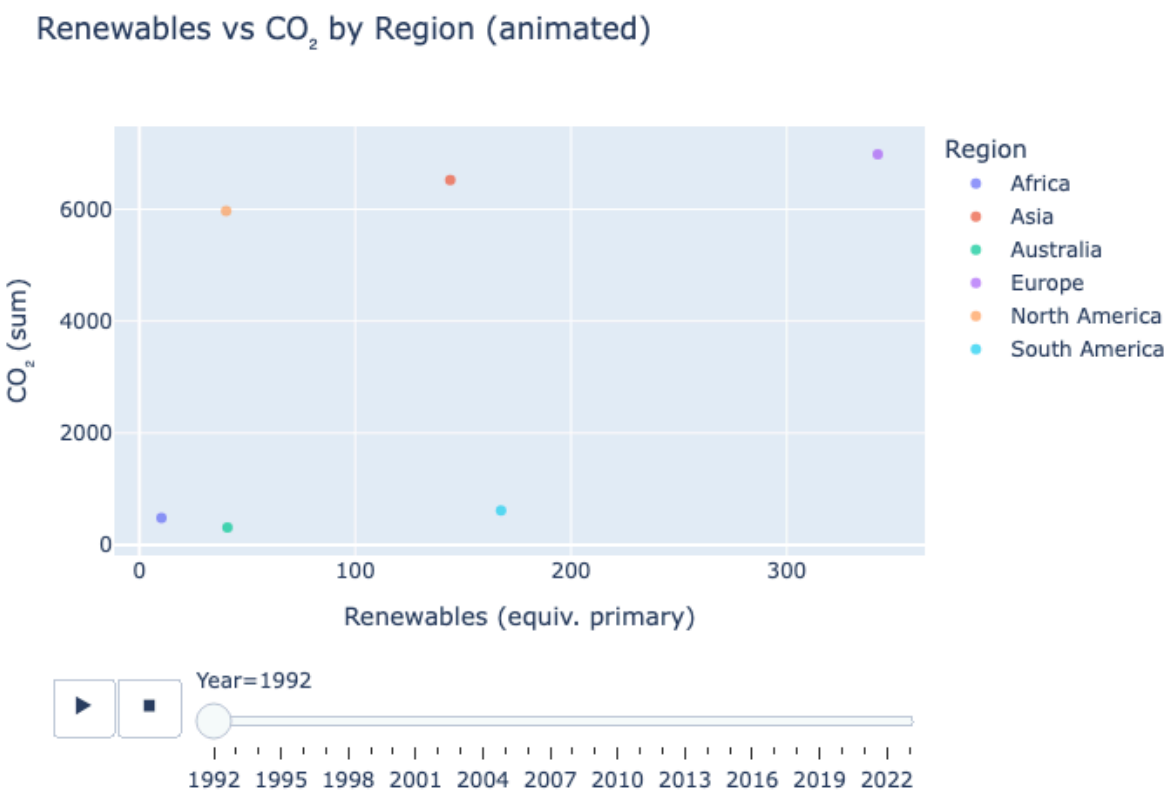
Regional CO_2 over Time (e.g., Africa, Europe, Asia)

- **Description:** Line charts with markers; X-axis: Year (1992–2023); Y-axis: CO_2 sum (Mt); Blue line per region.
- **Data Insights:** Europe declines from ~6,979 Mt (2000) to ~4,906 Mt (2023); Asia surges to ~20,000+ Mt; Africa rises to ~900+ Mt.
- **Trends and Interpretation:** Europe's decline post-2010 aligns with renewables surge (-0.949 correlation); Asia's exponential growth reflects industrial demand (0.336).
- **Actionable Insights:** Negative correlations in Europe/North America confirm renewables' effectiveness; positive in Asia/Africa signals insufficient fossil replacement.
- **Recommendations:** Scale renewables in Asia (target 500+ units by 2030); adopt Europe's subsidy models.



Regional Renewables over Time

- **Description:** Similar; Y-axis: Renewables sum (units).
- **Data Insights:** Europe to ~815 units, Asia ~185+, Africa ~17.
- **Trends:** Europe's steady rise; Asia's post-2010 boom; Africa's volatility (e.g., 3.419 YoY growth in 2003).
- **Insights:** High renewables correlate with CO_2 drops only in Europe/North America.
- **Recommendations:** Fund solar/wind in Africa ($50B annually); replicate Germany's grid investments.



Animated Scatter: Renewables vs CO_2

- **Description:** Scatter plot; X: Renewables sum; Y: CO_2 sum; colored by region; animated by Year (slider).
- **Data Insights:** Europe moves left-up (more renewables, less CO_2); Asia right-up (both increase).
- **Trends:** Post-2010, Europe clusters lower; Asia dominates high-CO_2 quadrant.
- **Insights:** Visualizes decoupling success (Europe) vs. failure (Asia).
- **Recommendations:** Use animation for policy workshops; target Asia for tech transfers.

```
Correlation (renewables_sum vs co2_sum) by region:
  Europe          : -0.949
  North America   : -0.816
  South America   : -0.076
  Australia       :  0.141
  Asia            :  0.336
  Africa          :  0.352

Global correlation (renewables vs CO2, GHG):
                renewables_sum   co2_sum   ghg_sum
renewables_sum        1.000000  0.830570  0.820665
co2_sum               0.830570  1.000000  0.995935
ghg_sum               0.820665  0.995935  1.000000
```

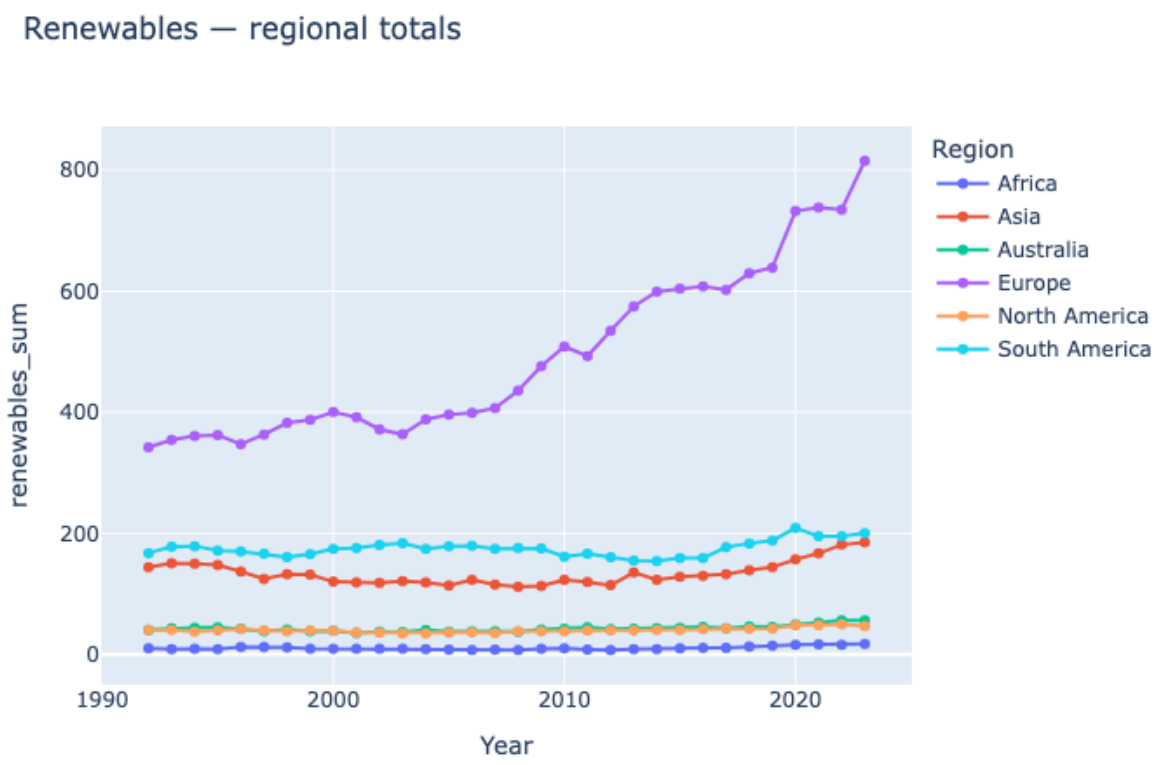
Global Correlations:

- **Data:** Renewables-CO_2 correlation: 0.831 globally.
- **Insights:** Positive correlation reflects co-growth; decoupling not global.
- **Recommendations:** Prioritize top emitters (China, US) for renewable scale-up.

Conclusion: Renewables reduce emissions where policies displace fossils (Europe); elsewhere, growth masks impact.

2.2 Which Regions/Countries Are Leading or Lagging in Renewables?

Answer: Leaders: Europe (highest sum, ~815 units), North America (~200 units); countries like Germany, Norway. Laggers: Africa (~15 units), parts of Asia (e.g., oil-rich nations); countries like Algeria (volatile), Saudi Arabia (low adoption).



Renewables — Regional Totals

- **Description:** Multi-line chart; X: Year; Y: Renewables_sum; colored lines (e.g., Europe blue, Asia red).

- **Data Insights:** Europe leads (342 to 815 units); Asia grows rapidly post-2010; Africa flat (~10–17).
- **Trends:** Europe’s consistent rise; Asia’s exponential; Africa’s stagnation.
- **Insights:** Leaders have diversified grids; laggers rely on fossils or hydro.
- **Recommendations:** Invest $100B in Africa’s solar; replicate Norway’s hydro model.

Top Emitters:

	Country	co2_total
0	China	226520.825
1	United States	177570.130
2	Russia	52338.735
3	India	51249.237
4	Japan	38728.081
5	Germany	26770.964
6	Canada	17540.384
7	South Korea	16712.374
8	Iran	16335.493
9	United Kingdom	15811.423

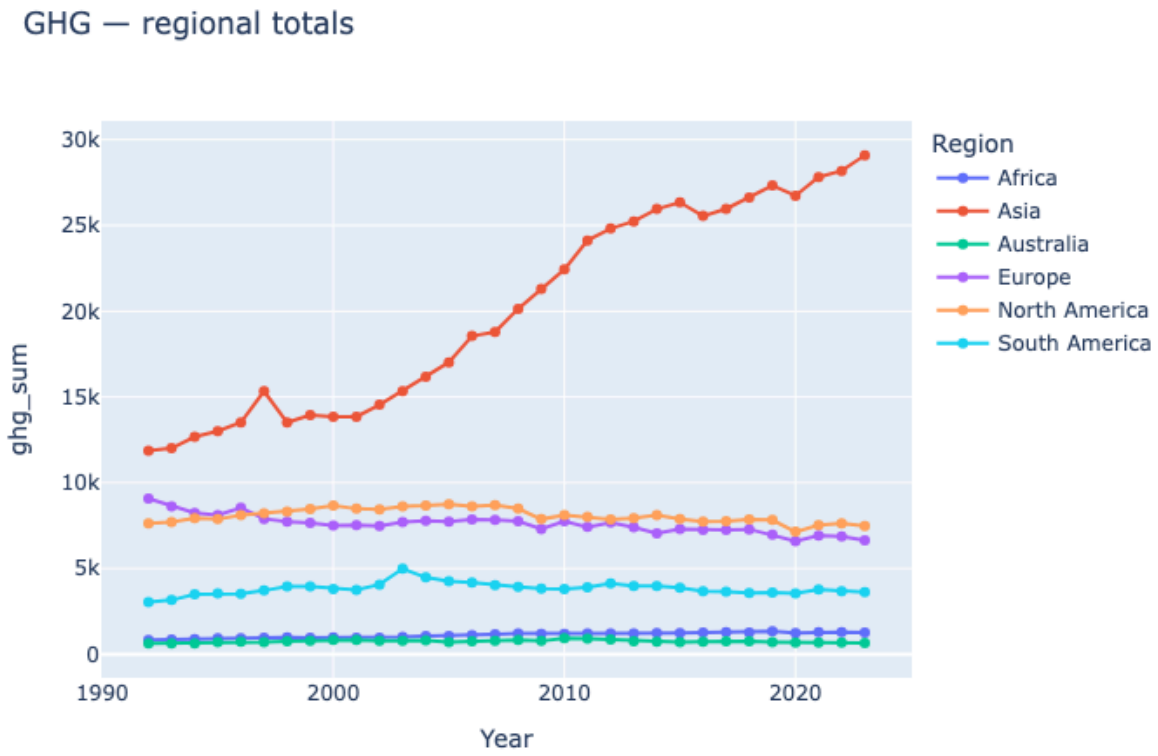
- **Data Table:**
  | Country | CO2_total (Mt) | |----------|----------| | China | 226,520.825 | | United States | 177,570.130 | | Russia | 52,338.735 | | India | 51,249.237 |
- **Insights:** China/US lead emissions but also renewables (China’s sum high in Asia). Russia/Saudi lag in renewables share.
- **Recommendations:** Target China for solar scale-up; incentivize Russia’s transition.

Standouts: Germany (high renewables, declining CO_2); Algeria (volatile renewables, e.g., 1.769 YoY growth 1998).
Recommendations: Study Germany’s policies; stabilize Africa’s investment climate.

2.3 What Are the Patterns, Anomalies, or Turning Points in the Data?

Answer: Patterns: Global CO_2 up ~70%; renewables tripled. Regional: Europe declines post-2000; Asia exponential. Anomalies: 2001–2002 dips (economic);

Africa’s renewables volatility. Turning Points: Post-2010 renewables surge (policy-driven).

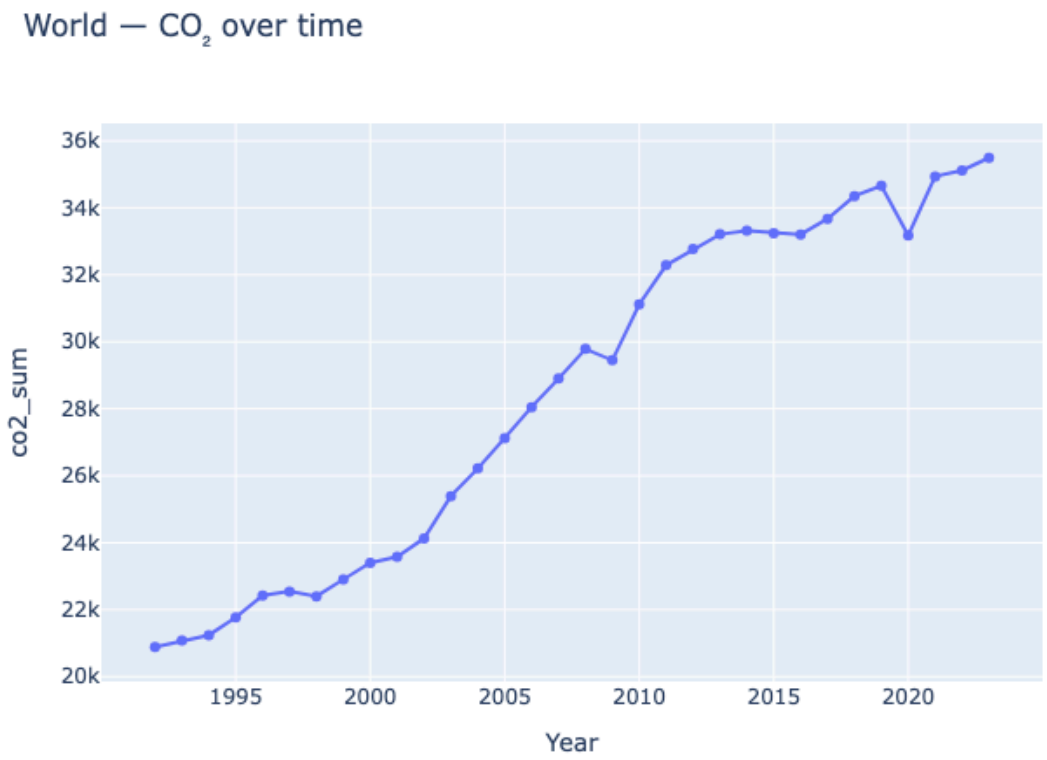


Regional GHG over Time

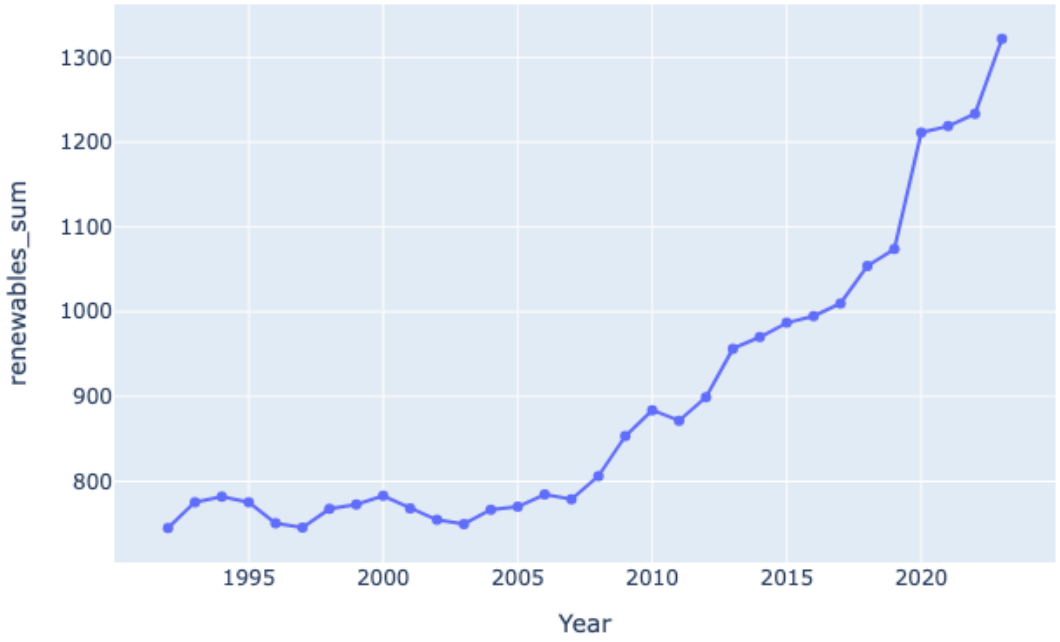
- **Description:** Line charts; Y: GHG sum (Mt CO_2eq).
- **Data Insights:** Asia ~29,000+ Mt; Europe ~6,633 (2023).
- **Trends:** Parallels CO_2; Africa’s GHG ~1.5x CO_2 (agriculture).
- **Insights:** Non-energy emissions significant; 2001 dip anomaly.
- **Recommendations:** Address methane in Africa via ag tech.

	Year	renewables_sum	co2_sum	ghg_sum	co2pc_avg
0	1992	744.997395	20886.752	33072.666	7.718406
1	1993	775.531717	21080.531	33005.724	7.674924
2	1994	781.927582	21241.517	33855.268	7.667623
3	1995	775.532782	21770.320	34187.243	7.691485
4	1996	750.712997	22421.046	35376.228	7.900804

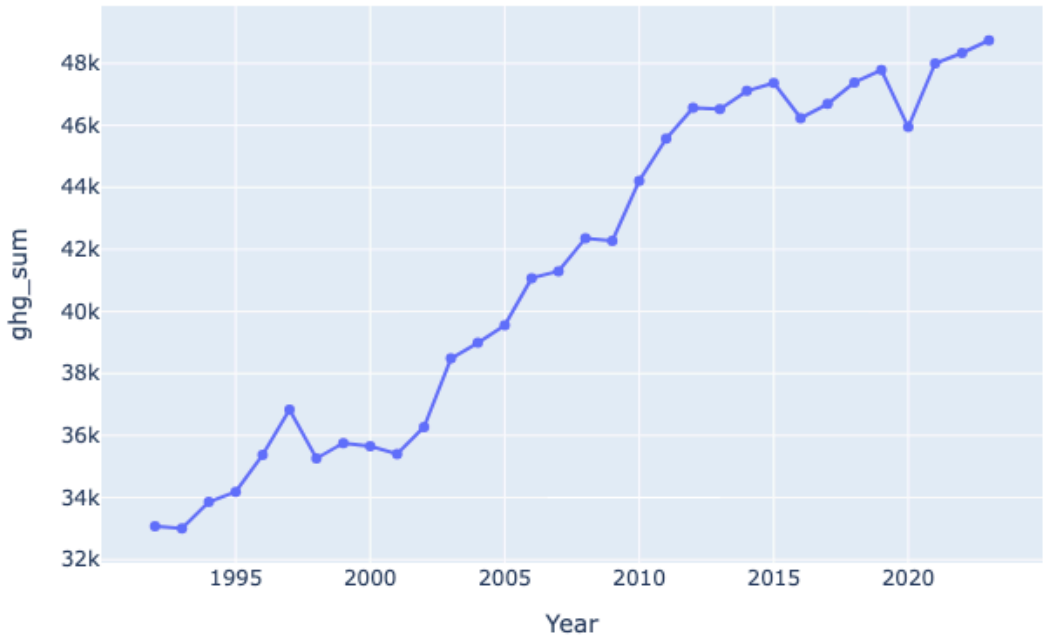
	count	mean	std	min	25%
Year	32.0	2007.500000	9.380832	1992.000000	1999.750000
renewables_sum	32.0	894.297235	168.116794	744.997395	769.641603
co2_sum	32.0	28496.461437	5160.303142	20886.752000	23277.116000
ghg_sum	32.0	41411.972500	5479.010976	33005.724000	35731.857000
co2pc_avg	32.0	8.261762	0.466070	7.398452	7.855204



World — Renewables over time



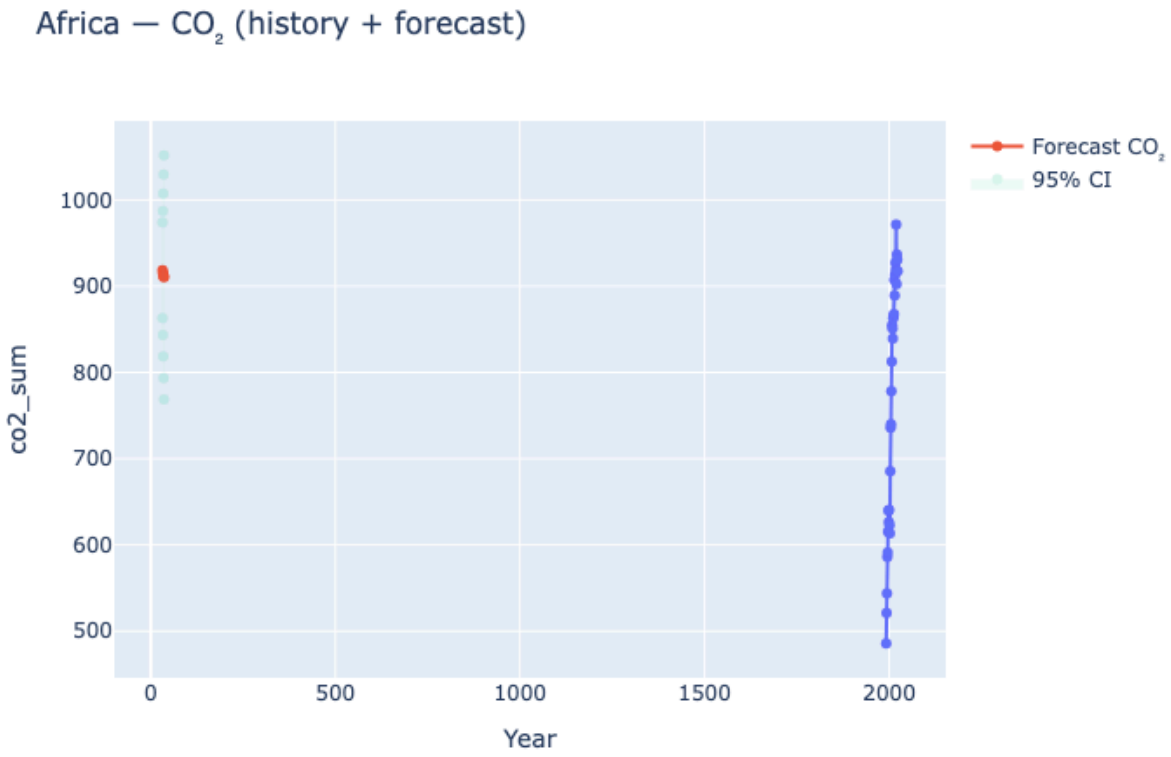
World — GHG over time

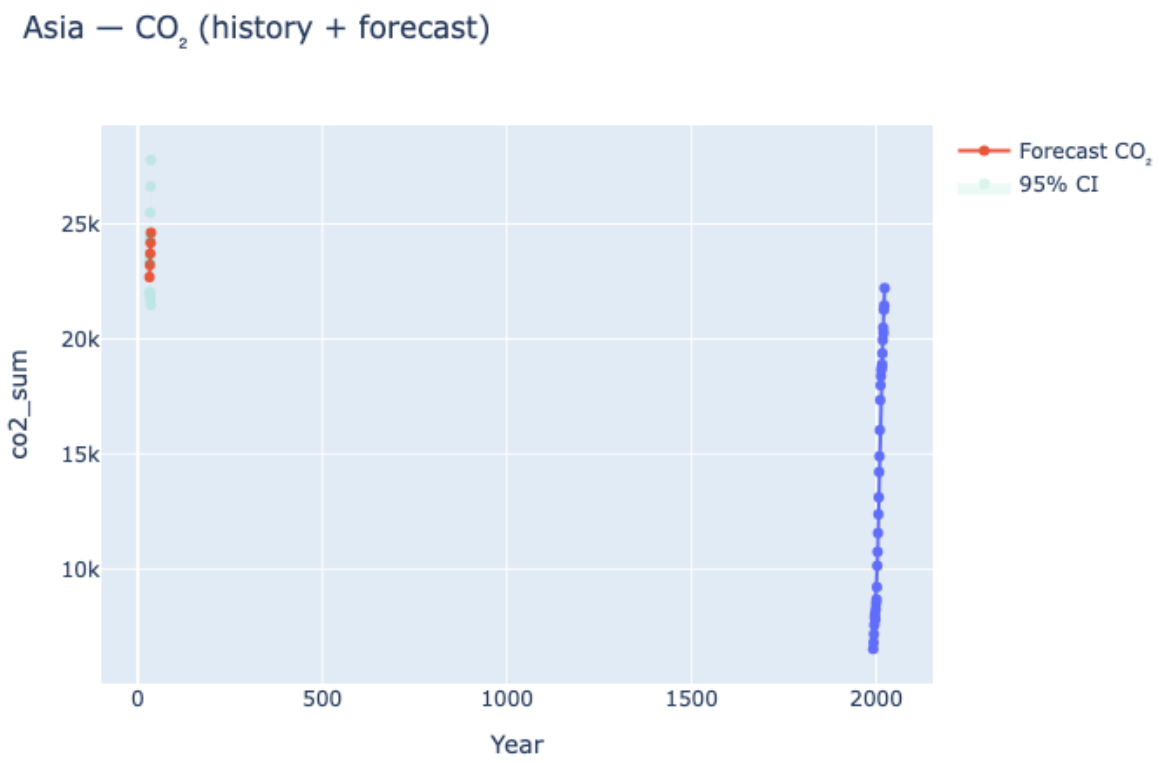


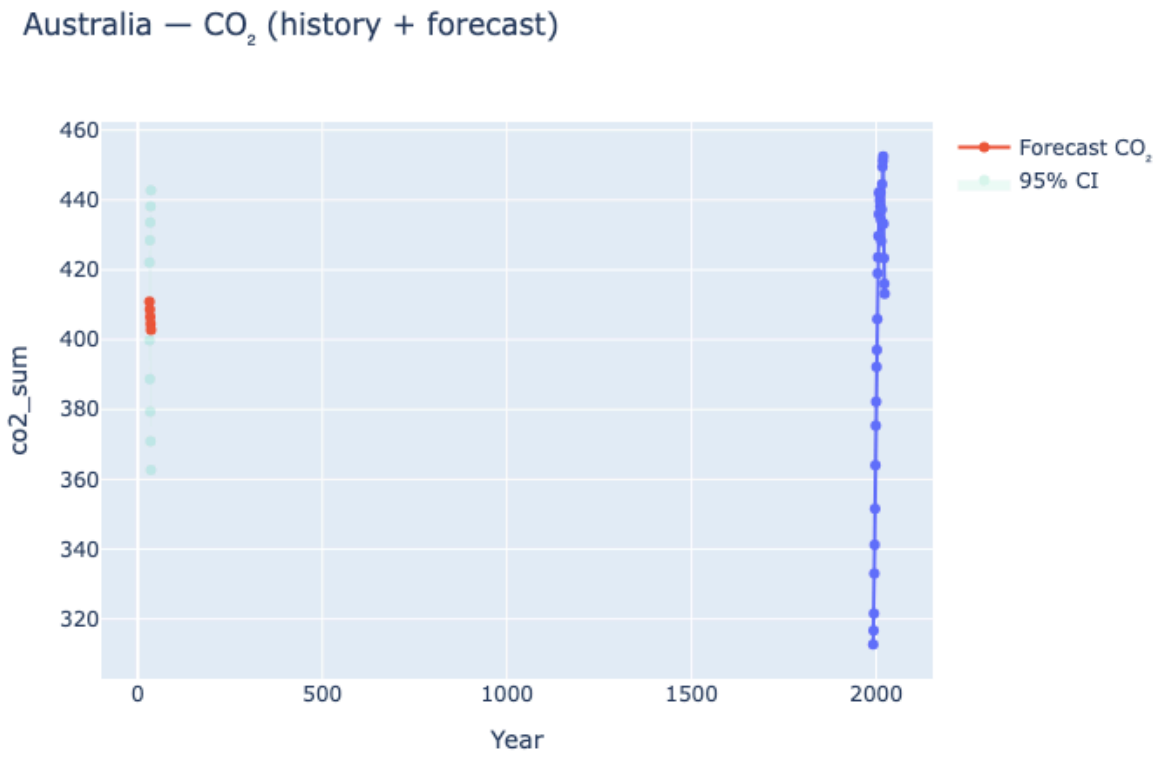
	renewables_sum	co2_sum	ghg_sum
renewables_sum	1.000000	0.830570	0.820665
co2_sum	0.830570	1.000000	0.995935
ghg_sum	0.820665	0.995935	1.000000

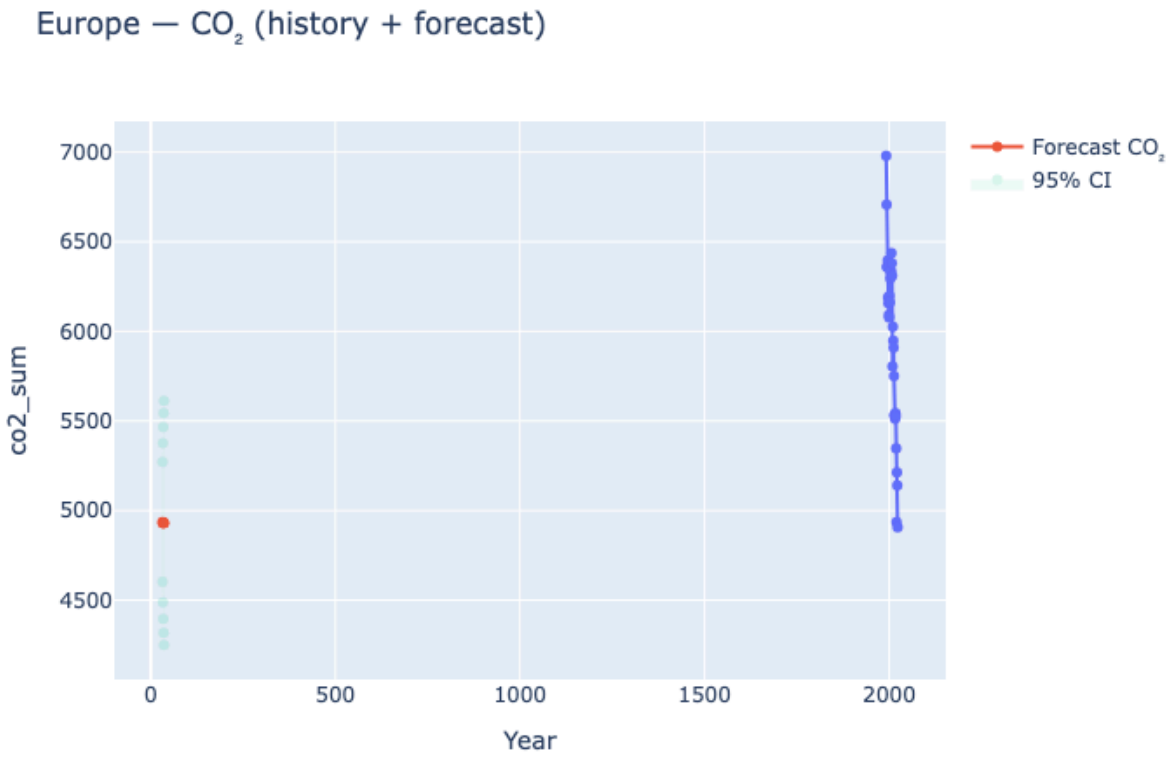
Global CO_2/Renewables/GHG (In [17]):

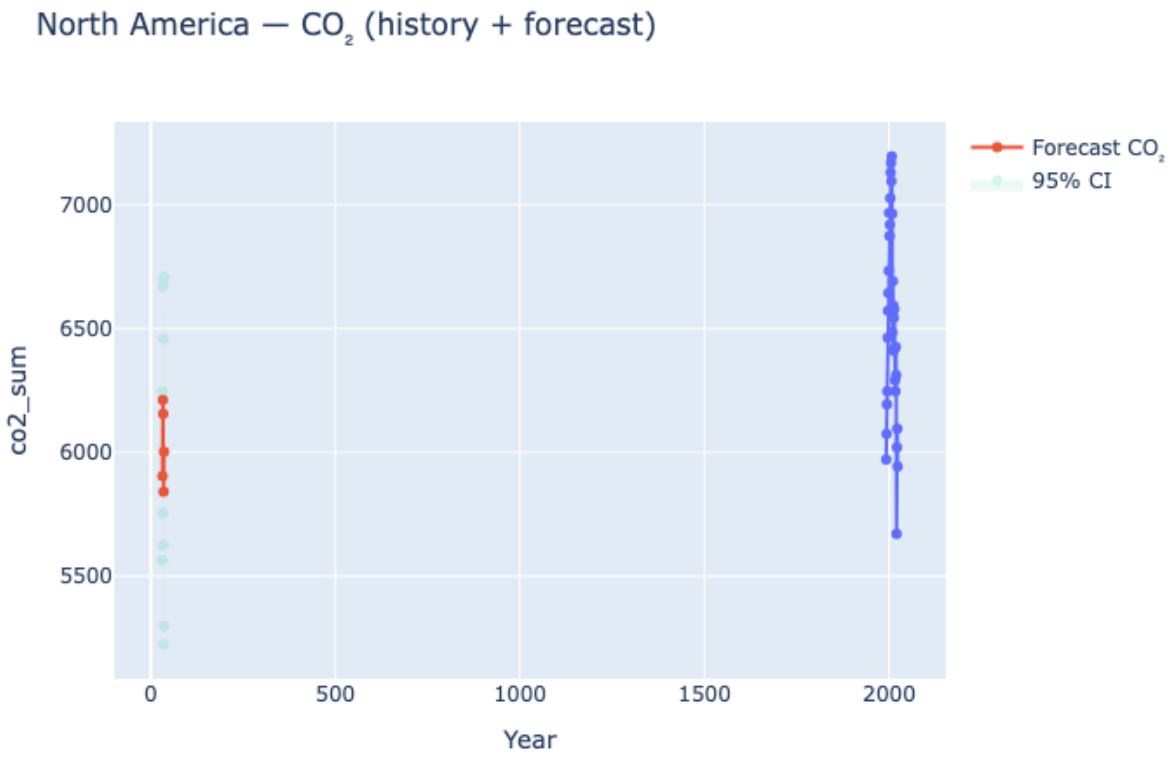
- **Description:** Line charts; Y: Respective sums.
- **Data Insights:** CO_2 from 20,887 to 35,495 Mt; renewables ~745 to 1,322 units; ghg ~33.1 to 48.7.
- **Trends:** CO_2 plateaus post-2020; renewables accelerate post-2010.
- **Insights:** Turning point ~2010 (global policies); 2020 dip (COVID).
- **Recommendations:** Analyze post-2010 policies for scaling.

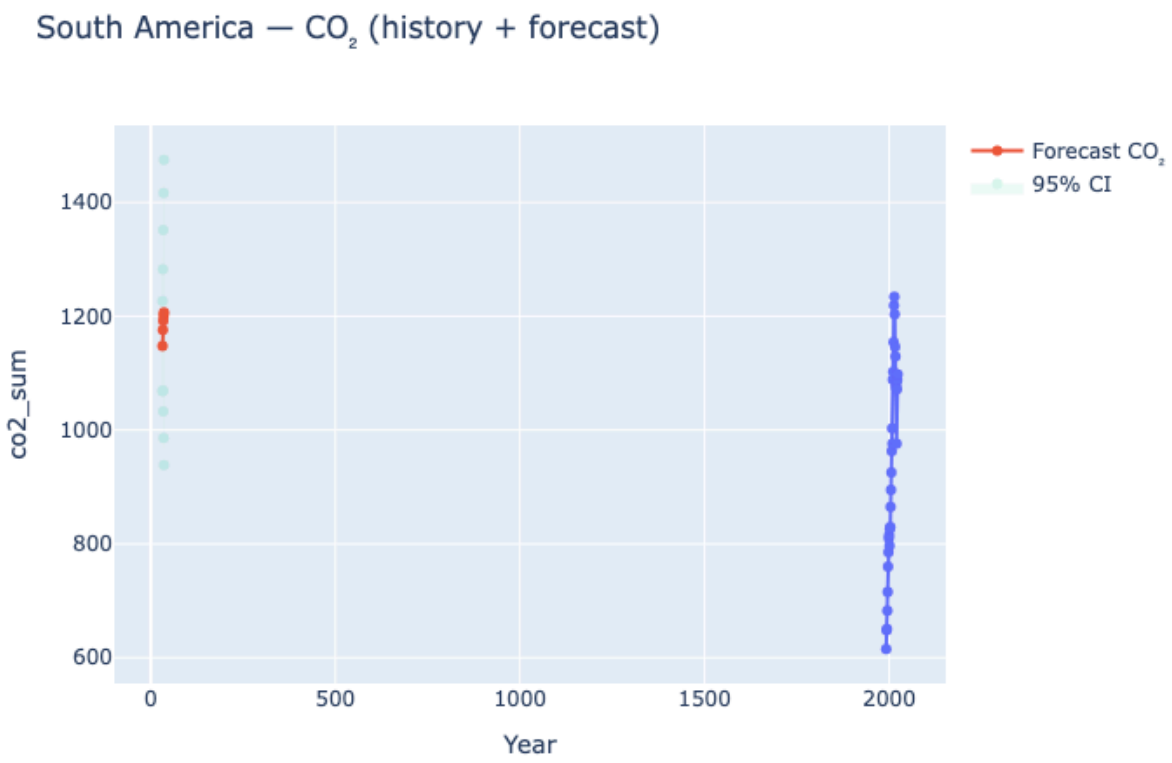



Asia — CO2 (history + forecast)
Forecast CO2
95% CI
co2_sum
25k
20k
15k
10k
0
500
1000
1500
2000
Year


Australia — CO2 (history + forecast)
Forecast CO2
95% CI
co2_sum
460
440
420
400
380
360
340
320
0
500
1000
1500
2000
Year


Europe — CO2 (history + forecast)
Forecast CO2
95% CI
co2_sum
7000
6500
6000
5500
5000
4500
0
500
1000
1500
2000
Year


North America — CO2 (history + forecast)
Forecast CO2
95% CI
co2_sum
7000
6500
6000
5500
0
500
1000
1500
2000
Year



9. **Regional Forecasts:**
    - **Description:** Lines with forecast (orange) and 95% CI bands.
    - **Insights:** Europe's decline continues; Asia/Africa rise.
    - **Recommendations:** Plan for Asia's growth; monitor CI for risks.

Conclusion: Post-2010 marks policy-driven renewable growth; anomalies highlight economic sensitivity.

2.4 How Do Per Capita Emissions Differ Between High- and Low-Renewables Countries?

Answer: High-renewables countries (e.g., Sweden, Norway) have ~5–7 t/person CO_2, 50–70% lower than low-renewables (e.g., Qatar, Kuwait: ~20–30 t). High-renewables align with lower per capita emissions.

	rows_total	countries	year_min	year_max
0	2405	79	1992	2023

	count	mean	std	min	25%	
renewables_sum	32.0	492.022107	139.721682	342.202977	379.858437	42
co2_sum	32.0	5949.680125	508.257336	4905.671000	5531.182000	608
ghg_sum	32.0	7585.959063	550.409359	6587.303000	7282.166750	760

	renewables_sum	co2_sum	ghg_sum
renewables_sum	1.000000	-0.949417	-0.834655
co2_sum	-0.949417	1.000000	0.929126
ghg_sum	-0.834655	0.929126	1.000000

Out[57]:

	Region	Year	renewables_sum	co2_sum	ghg_sum	co2pc_avg	countries
123	Europe	2019	638.858940	5347.597	6967.900	6.741088	34
124	Europe	2020	732.118604	4936.625	6587.303	6.096353	34
125	Europe	2021	738.422155	5213.931	6912.013	6.383088	34
126	Europe	2022	734.801800	5139.208	6865.071	6.167147	34
127	Europe	2023	815.263507	4905.671	6633.342	5.779559	34

	count	mean	std	min	25%	
renewables_sum	32.0	10.678871	2.812388	7.411706	9.076019	9.6
co2_sum	32.0	768.578531	147.492322	485.885000	625.641750	825.9
ghg_sum	32.0	1114.674875	153.366966	827.017000	964.337750	1171.1

	renewables_sum	co2_sum	ghg_sum
renewables_sum	1.000000	0.352011	0.360158
co2_sum	0.352011	1.000000	0.999081
ghg_sum	0.360158	0.999081	1.000000

Out[58]:

	Region	Year	renewables_sum	co2_sum	ghg_sum	co2pc_avg	countries
0	Africa	1992	10.201364	485.885	827.017	3.09500	4
1	Africa	1993	8.836401	521.346	864.199	3.22875	4
2	Africa	1994	9.914224	543.803	879.627	3.33275	4
3	Africa	1995	9.094689	586.215	937.433	3.52900	4
4	Africa	1996	12.497541	591.247	939.599	3.51725	4

Region-Year Aggregates:

- **Data Table (Sample):**

| Region | Year | co2pc_avg (t/person) | countries | |--------|------|---------------------|----------| | Africa | 1992 | 3.095 | 4 | | Europe | 2023 | 5.779 | 34 | - **Insights:** Europe ~5–7 t; North America ~6–8 t; Africa ~3–4 t (low renewables).
- **Recommendations:** Target high per capita countries (e.g., Qatar) for transition.

Interactive Dashboard:
- **Description:** Subplots (CO_2, Renewables, GHG, CO_2 per capita, etc); dropdowns for region/country; rangesliders.
- **Insights:** Norway ~5 t, Qatar ~25 t; high-renewables countries consistently lower.
- **Recommendations:** Deploy dashboard for boardroom analysis; compare countries. https://chiagoziemrenewabledashboard.streamlit.app/

Conclusion: High-renewables countries show lower per capita emissions; laggers need targeted interventions.

4. Actionable Insights and Recommendations

Insights:

- **Correlation Impact:** Europe/North America's negative correlations (-0.949, -0.816) prove renewables' efficacy; Asia/Africa's positive (0.336, 0.352) show scaling gaps.
- **Regional Leaders/Laggers:** Europe leads (815 units); Africa lags (~15). China's high renewables don't curb CO_2.
- **Patterns:** Post-2010 turning point; 2001/2020 anomalies (economic/COVID).
- **Per Capita:** High-renewables countries ~5–7 t/person; low ~20+ t.

Recommendations:

1. **Policy:** Adopt Europe's subsidies in Asia/Africa; target 20% renewables share by 2030.
2. **Investment:** Allocate $200B to Africa's solar/wind; prioritize China/US (40% emissions).
3. **Monitoring:** Deploy Streamlit dashboard (In [24]) for KPIs; update SARIMAX yearly.
4. **Corporate ESG:** Benchmark against Germany; set per capita CO_2 targets <7 t by 2030.

5. Conclusion

Renewables reduce emissions where policies enable displacement (Europe), but global doubling of CO_2 shows insufficient scale. Stakeholders should prioritize

high-emitter transitions, monitor via dashboards, and invest in laggers to meet net-zero goals.

Appendix:

- **Data:** 2,405 rows, cleaned via pandas; SQL for aggregates.
- **Limitations:** No GDP/policy data; assumes continuity.
- **Next Steps:** Run Granger tests on lags; integrate with ESG reports.

Column	Meaning / Description
Year	Calendar year of the observation.
Region_Canonical	Standardized name of the region (e.g., Europe, Asia).
Country	Country name within the region.
Label	Display label for region/country (used in charts and dashboards).
CO2	Total CO_2 emissions in **megatonnes (Mt)** for that year.
Total_GHG	Total greenhouse gas emissions in **CO_2-equivalent (Mt CO_2eq)**.
CO2_per_capita	CO_2 emissions per person in **tons per capita**.
Renewables_equivalent_primary_energy	Energy generated from renewables expressed in **primary energy equivalent** (e.g., PJ or TWh).
CO2_grow_yoy	Year-over-year percentage growth of CO_2 emissions. Positive means increase, negative means decrease.
Renewables_grow_yoy	Year-over-year growth of renewable energy production in %.
CO2_per_renewable_unit	Carbon intensity per unit of renewable energy (CO_2 emissions per renewable energy unit).

Column Explanations

1. **Country**
    - The name of the country the data point refers to.
    - Example: *Nigeria, Germany, United States*.
2. **Year**
    - The calendar year of observation.
    - Example: *2010, 2015, 2020*.
3. **Renewables_equivalent_primary_energy**

- The amount of renewable energy consumed or produced, expressed in **primary energy equivalents**.
- Primary energy equivalent means adjusting electricity from renewables (like wind, solar, hydro) into an equivalent amount of primary fuel that would otherwise have been required.
- Units often: **Exajoules (EJ)**, **Terawatt-hours (TWh)**, or **Million tonnes of oil equivalent (Mtoe)**.

4. **CO2**

   - Total **carbon dioxide emissions** from the country in that year.
   - Usually measured in **million tonnes ($MtCO_2$)**.
   - Territorial emissions (from within the country's borders, not accounting for imports/exports).

5. **CO2_per_capita**

   - CO_2 emissions **per person** in the country.
   - Formula: `CO2 / Population`.
   - Units: **tonnes per person (tCO_2/person)**.

6. **Total_GHG**

   - Total **greenhouse gas emissions**, including CO_2 plus other gases like **methane (CH_4), nitrous oxide (N_2O), fluorinated gases**.
   - Units: usually in **CO_2-equivalent ($MtCO_2e$)**, meaning other gases are converted into CO_2 terms using their global warming potential (GWP).

7. **UN_Region**

   - The official **United Nations geographic classification** of the country's region.
   - Example: *Africa, Europe, Asia, Latin America, Oceania, Northern America*.

8. **Region_Canonical**

   - A simplified or standardized region grouping, often used for analysis (could be broader or different from UN categories).
   - Example: *Sub-Saharan Africa, Middle East, Western Europe, North America*.

9. **Renewables_grow_yoy**

   - The **year-over-year growth rate of renewable energy** in percentage terms.

   - Formula:

$$\text{Growth}_t = \frac{\text{Renewables}_t - \text{Renewables}_{t-1}}{\text{Renewables}_{t-1}} \times 100$$

   - Shows how fast renewables are increasing (or decreasing) each year.

10. **CO2_grow_yoy**

- The **year-over-year growth rate of CO_2 emissions** in percentage terms.
- Formula:

$$\text{Growth}_t = \frac{\text{CO2}_t - \text{CO2}_{t-1}}{\text{CO2}_{t-1}} \times 100$$

- Positive = emissions rising, Negative = emissions falling.

11. **CO2_per_renewable_unit**

- A ratio showing how many tonnes of CO_2 are emitted **per unit of renewable energy**.
- Formula:

$$\frac{\text{CO2 emissions}}{\text{Renewable energy consumption}}$$

- Interpretation: Lower values suggest a cleaner energy mix (more renewables relative to emissions).