Growth, Emissions, and Renewables: A Cross-Country Analysis (1960–2022)

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2025-05-19

Introduction

Aligning economic growth with environmental sustainability is one of the most urgent challenges of our time. While higher incomes are typically associated with improved living standards, they also tend to go hand in hand with increased greenhouse gas emissions.

A central question is if wealthier countries can decouple economic prosperity from environmental harm by shifting their energy mix towards renewable sources, or if they continue to rely heavily on conventional, carbon-intensive energy production.

In this project, I use World Bank Data indicators to explore:

1. **Is there a relationship between a country's economic prosperity and its CO_2 emissions?**
2. **Which countries invest the most in renewable energy, and is there a pattern?**
3. **How do selected countries (China, Germany, Colombia) compare over time?**

The analysis is based on country-level data and ranges from 1965–2022. It is important to note that the African countries can not be considered in this project due to limited data availability.

Data Cleaning

As a first step, I restricted the time range to 1965–2022 to ensure consistency across datasets. This period is particularly relevant, as most major structural changes in terms of environmental sustainability have occurred since the late 20th century (Infante-Amate et al., 2025). The original datasets combined observations at both the national and regional level (e.g., World, Europe, Africa). For this study, only national data were retained, as the research question concerns country-level relationships between prosperity and emissions. Regional aggregates were removed by filtering out entries without ISO country codes, which uniquely identify countries. Moreover, rows where the main indicator variable was empty (NA), an empty string, or equal to zero were removed to avoid distortions. Variable names such as "Annual.CO..emissions..per.capita" were standardized for easier handling. An unnecessary annotation column in the GDP dataset was dropped. To streamline the process, I wrote a helper function clean_data() that applies the same cleaning rules to each dataset and reports how many rows were dropped. This cleaning ensures that the merged dataset contains only valid, country-level, and comparable observations.

Data Analysis

GDP, CO_2 Emissions and Energy Consumption

Focusing on the first research question, I examine whether richer countries emit more CO_2 per capita. To test this, I regress log CO_2 emissions per capita on log GDP per capita, first without and then with year fixed effects. The analysis is then extended by regressing log CO_2 emissions per capita on log energy use per capita, in order to assess whether energy consumption accounts for the increase in greenhouse gas emissions.

Table 1: OLS Regressions

	OLS: log CO2 ~ log GDP	OLS: log CO2 ~ log GDP (Year FE)	OLS: log CO2 ~ log Energy	OLS: log CO2 ~ log Energy (Year FE)
log GDP (per capita)	1.32446***	1.37689***		
	(0.00698)	(0.02254)		
log Energy use (kWh pc)			0.94742***	0.94587***
			(0.00242)	(0.00249)
R2	0.799	0.819	0.941	0.943
Adj. R2	0.799	0.818	0.941	0.943
Num. Obs.	9051	9051	9572	9572
Fixed effects (Year)	No	Yes	No	Yes

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The regression results in Table 1 show a strong and highly significant relationship between income and emissions. The baseline model reveals that a 1% increase in GDP per capita is associated with a 1.32% increase in CO_2 emissions per capita, while controlling for year fixed effects yields a similar coefficient of 1.38%. When replacing GDP with energy consumption, the coefficients are close to 1, indicating that higher energy use translates almost proportionally into higher emissions. Overall, the results suggest that both economic prosperity and energy use are tightly linked to environmental impact, with energy consumption acting as a direct channel through which income growth drives emissions.

Figure 1 plots the relationship between GDP per capita and CO_2 emissions per capita. The fitted line confirms the conclusion derived from the regression results in Table 1: higher incomes are generally associated with higher emissions. However, the scatter also reveals important variation. At low and middle income levels, emissions rise sharply with income, whereas at higher levels the trend appears to flatten, with some countries even showing lower emissions despite higher GDP. Thus, the scatterplot suggests that beyond a certain threshold, factors such as energy efficiency, renewable adoption, or environmental regulation may begin to offset the income–emissions link.

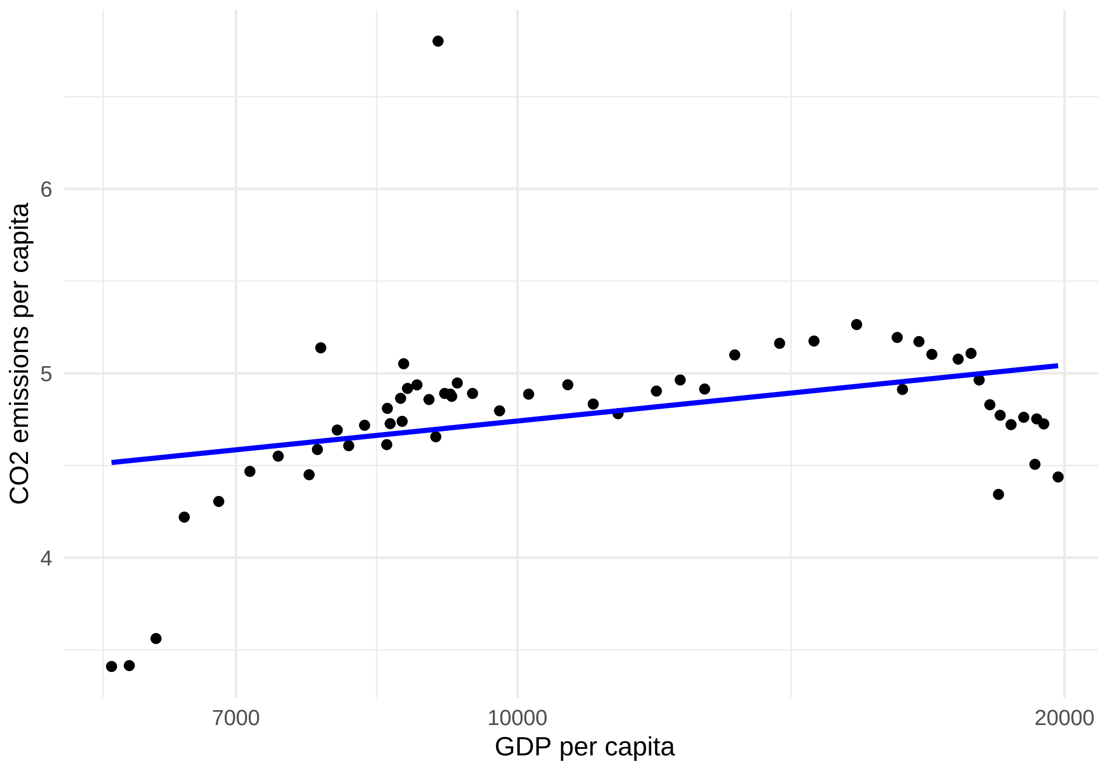

Figure 1: GDP per Capita vs CO2 Emissions per Capita

Energy Use and Renwables

After examining the relationship between income, energy use, and CO_2 emissions, I turn to the second research question: whether richer countries invest more in renewable energy. To address this, I regress the share of renewables in total energy consumption on GDP per capita, both with and without fixed effects. This approach allows me to examine whether economic prosperity is associated with greater reliance on renewable energy sources or whether renewable adoption is instead driven by other factors.

Table 2: OLS Regressions

	OLS: log Renewables ~ log GDP	OLS: log Renewables ~ log GDP (Year FE)
log GDP (per capita)	-0.09575**	-0.15512***
	(0.03507)	(0.02928)
R2	0.002	0.013
Adj. R2	0.002	—
Num. Obs.	3865	3865
Fixed effects (Year)	No	Yes

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2 indicates a negative and statistically significant relationship between GDP per capita and renewable energy share. For instance, column reveals that a 1% increase in GDP per capita is associated with a roughly 0.1% decrease in the share of renewables. When controlling for year fixed effects, the negative association becomes slightly stronger.

These findings suggest that, over the period considered, wealthier countries have not necessarily relied more on renewable energy. The appear to rely relatively less on renewables compared to poorer countries. One explanation could be that many high-income economies remain strongly dependent on fossil fuels to sustain industrial output and consumption. For example, several oil-rich countries in the Middle East maintain high levels of income from petroleoum exports, while domestic energy supply is almost entirely based on oil and gas rather than renewables.

Leaders in Renewable Energy

After establishing that the richest countries do not necessarily invest the most in renewable energy, I turn to the 20 countries with the highest renewable energy shares in 2022. Examining this group may provide insights into common patterns and highlight the types of economies that are leading in renewable adoption.

Table 3: Top 20 Countries by Share of Renewable Energy (2022)

Country	Year	GDP per capita	CO2 emissions (tons per capita)	Energy use (kWh per capita)	Renewables share (%)
Iceland	2022	42145.59	9.50	167551.89	82.08
Norway	2022	88366.22	7.48	97781.13	69.65
Sweden	2022	47126.13	3.57	59279.47	52.43
Brazil	2022	14640.08	2.30	17744.20	47.66
New Zealand	2022	38250.12	6.16	45347.65	43.29
Denmark	2022	50689.68	4.82	32904.23	40.79
Austria	2022	43792.86	6.78	42122.32	35.13
Finland	2022	40701.46	6.53	57499.90	34.90
Switzerland	2022	63323.25	3.73	33835.41	31.10
Canada	2022	45529.64	14.18	102122.55	29.50
Portugal	2022	28992.06	3.91	25206.77	28.75
Ecuador	2022	10124.08	2.27	12495.52	28.43
Colombia	2022	14468.96	1.90	12123.16	28.38
Latvia	2022	27220.30	3.52	20474.74	26.65
Venezuela	2022	5267.18	3.10	22898.95	26.48
Peru	2022	12762.97	1.64	10099.04	26.16
Chile	2022	22740.72	4.22	25750.82	26.08
Vietnam	2022	8050.36	2.99	12976.39	25.31
Croatia	2022	26986.75	4.51	23846.33	25.05
Sri Lanka	2022	10705.48	0.87	4265.71	23.45

Table 3 shows that the global leaders in renewable energy are not necessarily the wealthiest countries. While high-income countries such as Iceland, Norway, and Sweden achieve very high shares thanks to their abundant hydropower and geothermal resources (Zhong et al., 2021), many middle-income countries—especially in Latin America—also rank among the top performers. In addition, poorer countries such as Vietnam and Sri Lanka demonstrate that high renewable shares are not exclusive to high-income economies. These findings therefore suggest that natural resource endowments and energy structures play a greater role in determining renewable adoption than income levels alone.

Country Comparisons: China, Germany and Colombia

To illustrate different development trajectories, I compare GDP per capita over time in China, Germany, and Colombia. These three countries were chosen because they represent distinct economic and energy pathways: China as a rapidly industrializing economy, Germany as a wealthy nation pursuing an energy transition, and Colombia as a middle-income country with comparatively strong reliance on renewables.

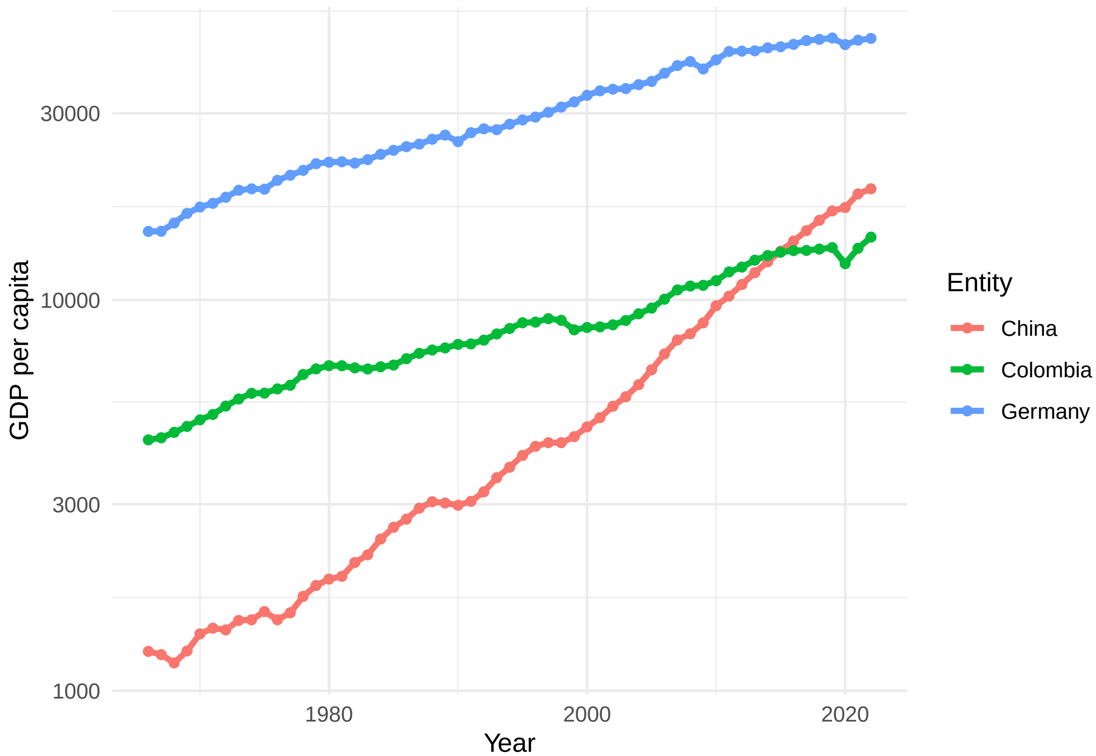

Figure 2: GDP per capita over time

Figure 2 illustrates significant differences in income levels. Germany has consistently maintained the highest GDP per capita, reflecting its status as a high-income industrialized economy. In contrast, China started from a much lower base but has experienced extraordinarily rapid growth since the 1980s, steadily narrowing the gap with advanced economies. Colombia, by comparison, has grown at a steady but more moderate pace, remaining below both Germany and China. This comparison highlights how economic growth trajectories diverge depending on historical, structural, and policy contexts, setting the stage for the differences in energy consumption and renewable energy adoption examined in the following figures.

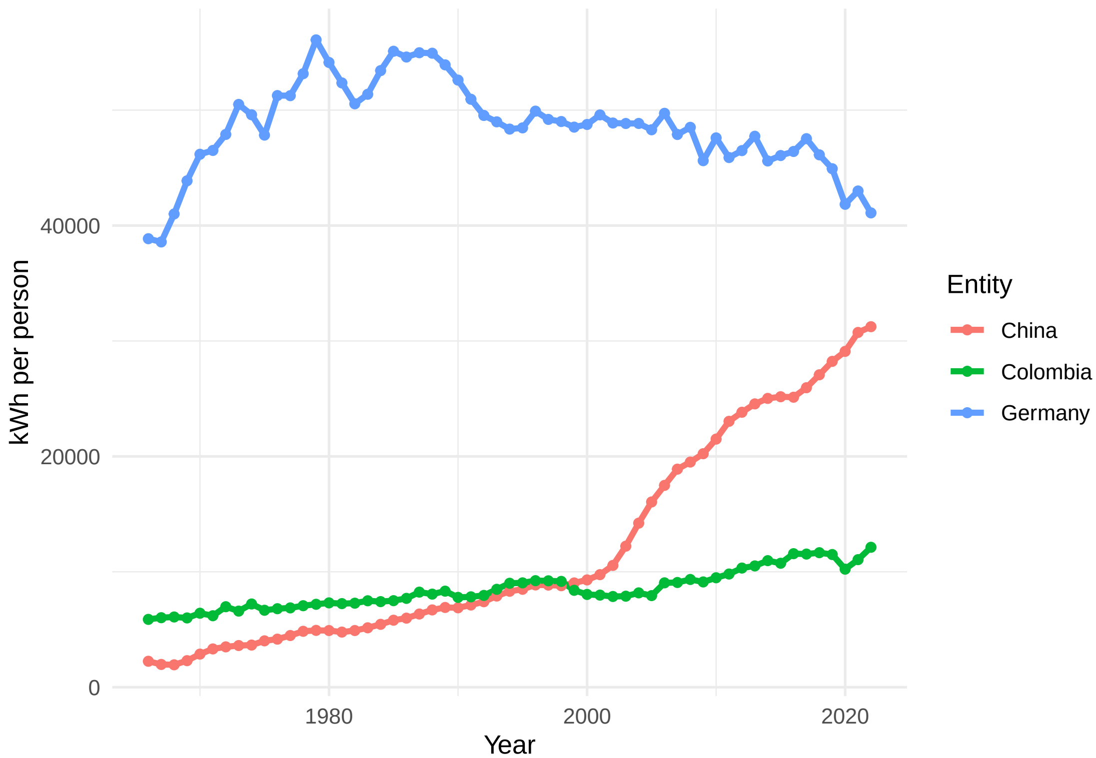

Figure 3: Energy Consumption per Capita over Time

Figure 3 shows trends in energy consumption per capita. Germany consistently exhibits a high level of energy use, reflecting its advanced industrial structure and high living standards. Although energy use has declined since the early 2000s, it remains far above that of China and Colombia. Mirroring its rapid industrialization and economic expansion, China has experienced a dramatic surge in energy consumption since the late 1990s. Today, it has overtaken Colombia and continues to rise steeply, though per capita consumption is still lower than in Germany. Colombia displays relatively stable but modest levels of energy use, with only gradual increases over time. This pattern reflects its more moderate economic growth and different industrial composition. In summary, these trajectories underscore the strong link between energy consumption and economic development, while also highlighting differences in national energy intensity and efficiency.

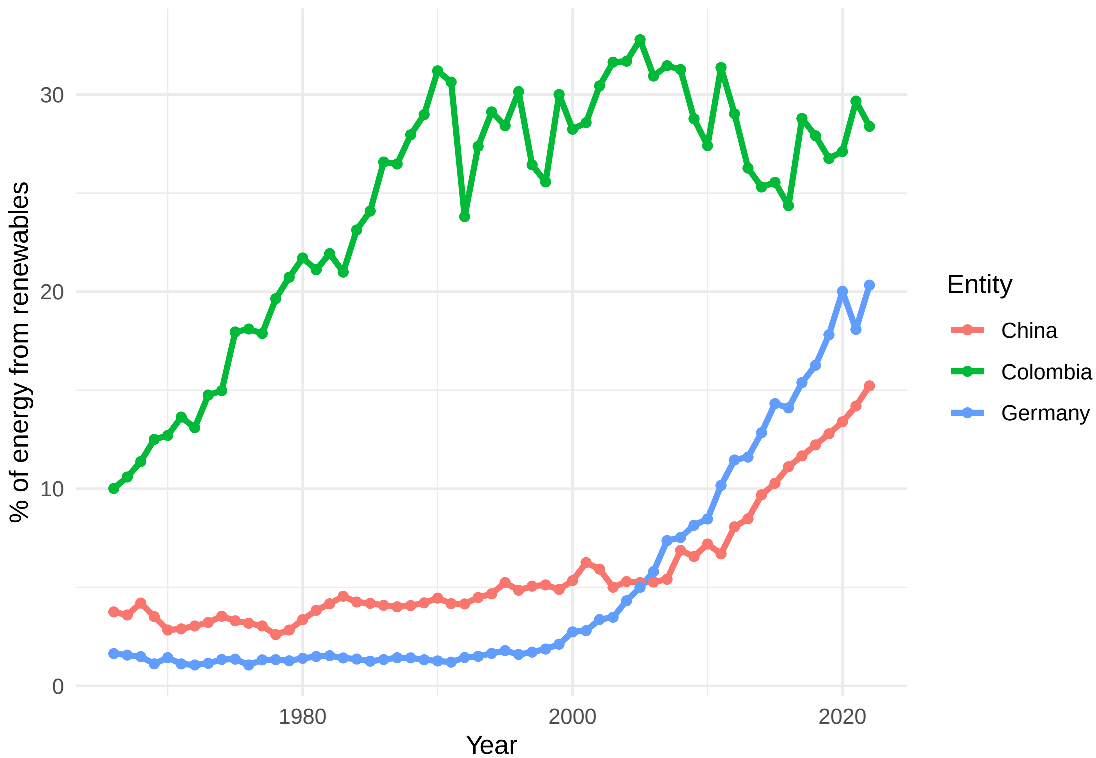

Figure 4: Renewable Energy Share over Time

Figure 4 illustrates the share of energy from renewable sources over time. Colombia has long relied on a comparatively high share of renewables, primarily due to its abundant hydropower resources (Parra et al., 2020). Its renewable energy share peaked at around 30% in the late 20th century and has since fluctuated but remained relatively stable between 25% and 30%, placing Colombia well above Germany and China throughout the entire period. In contrast, Germany began with a very low share of renewables but has experienced a steep and sustained increase since the early 2000s, reflecting its ambitious policies and substantial investment in wind and solar energy. As a result, renewables now account for roughly 20% of its energy mix, signaling a structural shift toward sustainability. Until about 2010, China recorded only gradual increases, but in recent decades renewable adoption has accelerated considerably. Despite this growth, renewables still represent a smaller share of China's overall energy mix compared with Germany or Colombia, underscoring the scale of its continued reliance on fossil fuels. Taken together, Figure 4 highlights three distinct pathways: Colombia's resource-driven reliance on renewables, Germany's policy-driven expansion, and China's late but rapid push toward diversification.

Conclusion

This project reveals a clear pattern: higher incomes and higher energy use are almost always associated with higher CO_2 emissions. Economic growth and pollution still tend to go hand in hand. When it comes to renewables, however, income alone does not explain adoption. Many smaller or middle-income countries achieve high renewable shares thanks to hydropower or other natural resources, while wealthy economies often remain locked into fossil fuels. The comparison between China, Germany, and Colombia illustrates three distinct pathways: China's rapid growth has fueled rising emissions, Germany has invested heavily in renewables, and Colombia benefits from abundant hydropower despite more modest income levels. Overall, decoupling growth from emissions does not occur automatically. It depends on policy choices, technological innovation, and energy structures. With the right strategies, prosperity and sustainability need not be a trade-off; they can reinforce one another.

References

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