

ORIGINAL RESEARCH

Renewable Energy, Economic Growth, and CO₂ Emissions: A Comparison of the United States and China (1990–2024)

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Abstract

Since 1990, the United States and China have followed nearly opposite paths on carbon emissions. The U.S. has cut its CO₂ output by about 30 percent from its 2005 peak, even as its economy has grown steadily. China, meanwhile, has seen emissions nearly triple over the same period as it industrialised at extraordinary speed. This paper tracks both countries from 1990 to 2024, using freely available data from the World Bank, EDGAR, and the IEA. Simple statistical tools in Excel—percentage changes, correlations, and linear regression—show that economic growth and emissions move in opposite directions in the United States ($r = -0.78$) but rise together in China ($r = +0.96$). One pattern holds across both economies: wherever renewable energy use expands, emissions tend to fall. These results suggest that shifting toward clean energy can help separate economic growth from pollution, though the timing and scale of that shift depend heavily on each country's industrial structure. The project also reflects on the practical value of working directly with raw data as a capstone exercise at the secondary-school level.

Keywords: Renewable Energy; Economic Growth; CO₂ Emissions; United States; China; Correlation; Regression; High School Research Project

1. Introduction

Fossil-fuel-driven economic growth since the Industrial Revolution has raised the global average temperature by roughly 1.1°C. Most of that warming has occurred in the last seventy years, as industrial production, transportation, and household energy use expanded on a scale earlier generations could not have imagined. Meeting the 1.5°C target set out in the Paris Agreement will require a fundamental transformation of energy systems, touching everything from how electricity is generated to how goods are manufactured and shipped around the world.

The United States and China together account for close to 40 percent of global CO₂ emissions, which makes the energy policies of these two countries central to the future of the global climate. No credible path to stabilizing the global climate exists without significant emissions reductions from both nations,

yet the two economies differ enormously in structure, income level, and stage of industrial development. The United States built its wealth over more than a century of industrialization before gradually shifting toward a service-based economy, while China has compressed a similar transformation into roughly four decades, becoming the world's manufacturing center in the process. These differences in economic history help explain why the same broad goal—reducing emissions while sustaining growth—looks so different in practice in Washington and Beijing.

It is also worth noting that emissions trends are not simply a matter of national choice; they are tied closely to global trade patterns. A portion of the goods manufactured in China, and the emissions associated with producing them, are ultimately consumed in the United States and other wealthy countries. This complicates any simple comparison of “who pollutes more,” since production-based emissions statistics (used throughout this paper, as they are the most widely available) do not fully capture where the underlying demand for goods originates. This caveat is revisited in the discussion section.

As of 2024, the Gross Domestic Product (GDP) of the United States stood at approximately \$28.8 trillion, compared with roughly \$18.3 trillion for China. Together, the two countries account for a substantial share of global economic output and energy consumption. Understanding how their growth paths relate to their emissions is not just an academic exercise: decisions made in these two capitals over the next decade will do more to determine the trajectory of global warming than the combined policies of most other countries put together.

Beyond its global relevance, this project was designed to build statistical-analysis skills at the high-school level using open data published by international organizations. Rather than relying on secondary summaries or news reporting, the aim was to work directly with primary data sets, apply the same basic statistical tools used in introductory college coursework, and draw conclusions supported by evidence rather than assumption. In this sense, the project is as much an exercise in quantitative literacy as it is a study of climate policy.

1.1 Literature Review

Renewable energy sources—solar, wind, hydropower, geothermal, and biomass—generally have lower operating costs than fossil fuels and produce almost no direct CO₂ emissions. According to the International Energy Agency's 2023 report, renewables now supply roughly 30 percent of global electricity generation, a share that has grown steadily as the cost of solar panels and wind turbines has fallen. The IEA projects that this share will continue to rise through the end of the decade as more countries adopt supportive policies and battery storage becomes cheaper.

Some economists point to a theory suggesting that environmental pollution first rises and then falls as a country's income increases. Under this view, low-income economies pollute relatively little because they have not yet industrialized; as industrialization proceeds, pollution rises; and once a country becomes wealthy enough to prioritize environmental quality and shift toward services and cleaner technology, pollution begins to fall again. High-income countries such as the United States are frequently cited as being on the declining portion of this curve, while industrializing economies such as China may still be at a stage where emissions remain elevated. It should be noted that this theory is debated among economists, and not every country follows the pattern it describes—some skip the peak entirely by adopting cleaner technology early, while others plateau at a high level of emissions for decades.

Carbon intensity—the amount of CO₂ emitted per unit of GDP—is one of the key indicators used to understand the relationship between an economy and its environmental impact. When a country's emissions fall even as its economy grows, this is described as a “decoupling” of growth from emissions.

Absolute decoupling, in which total emissions fall in absolute terms, is considered the more meaningful benchmark than relative decoupling, in which emissions merely grow more slowly than the economy. As will be shown in Section 4, the United States has achieved a measure of absolute decoupling since 2005, while China's decoupling so far has been relative rather than absolute.

Finally, a growing body of research has examined how trade and supply chains affect national emissions accounting. Because many manufactured goods are produced in one country and consumed in another, some economists argue that consumption-based emissions accounting—which allocates emissions to the country where a good is ultimately used rather than where it is produced—gives a fuller picture of each country's environmental footprint. This paper relies on production-based data, which is the standard used by most publicly available data sets, but this limitation is kept in mind when interpreting the results.

2. Economic Development Structures of the United States and China

2.1 The United States: From Industrial Powerhouse to Service Economy

The structure of the U.S. economy has changed dramatically since the mid-twentieth century. In the decades following the Second World War, manufacturing was the backbone of American economic output, employing a large share of the workforce in sectors such as steel, automobiles, and heavy machinery. Manufacturing's share of GDP has fallen steadily since then, and today services—including finance, healthcare, technology, education, and professional services—account for roughly 80 percent of U.S. GDP, while manufacturing accounts for around 10 percent.

This shift, often referred to as deindustrialization, was driven by several forces: automation reduced the number of workers needed per unit of output, competition from lower-cost manufacturers abroad drew production overseas, and rising incomes increased demand for services relative to goods. The consequences for energy use and emissions have been significant. Services generally require far less energy per dollar of output than heavy industry, so as the U.S. economy has shifted toward services, its energy intensity—and by extension its carbon intensity—has fallen even before accounting for any change in the cleanliness of its energy supply.

A second major structural change has been the U.S. shift toward energy independence. For much of the late twentieth century, the United States imported a large share of its oil from abroad, which shaped its foreign policy and left it exposed to global price shocks. The development of hydraulic fracturing (fracking) technology after roughly 2008 unlocked vast reserves of domestic shale oil and gas, and by the late 2010s the United States had become a net exporter of petroleum products for the first time in decades. This had two effects relevant to this study: it made natural gas cheap and abundant domestically, accelerating the switch away from coal in electricity generation, and it reduced the strategic incentive to import oil, altering the political economy of U.S. energy policy in ways still being debated today.

The service-oriented, energy-independent structure of the U.S. economy also affects how it experiences economic downturns and recoveries. Because services make up such a large share of output, U.S. GDP tends to be less directly tied to industrial production and energy consumption than economies with a larger manufacturing base, which partly explains why U.S. emissions can decline even during years of positive GDP growth—a pattern examined in more detail in Sections 4 and 5.

2.2 China: From Planned Economy to Export-Led Manufacturing Giant

China's economic structure has followed an almost opposite trajectory over the same period. Prior to 1978, China operated under a centrally planned economy with limited international trade and low industrial

output relative to its population. The reforms launched under Deng Xiaoping beginning in 1978—often referred to as the “reform and opening up” policy—gradually introduced market mechanisms, permitted private enterprise, and opened the country to foreign investment and trade. Special Economic Zones established along the coast, such as Shenzhen, became testing grounds for market-oriented policies and attracted foreign manufacturers seeking low labor costs and favorable regulation.

Growth accelerated sharply after China’s accession to the World Trade Organization in 2001, which gave Chinese exporters much greater access to global markets and cemented the country’s role as the world’s leading manufacturer of everything from textiles and electronics to steel and machinery. Unlike the United States, where manufacturing’s share of GDP has fallen for decades, industry (including manufacturing and construction) still accounts for roughly 38 percent of China’s GDP, while services account for a smaller share of output than in the United States, at around 55 percent, and agriculture makes up most of the remainder.

This industrial structure has direct implications for energy demand and emissions. China’s economy remains heavily reliant on energy-intensive sectors such as steel, cement, chemicals, and aluminum production—industries that consume large amounts of electricity and, because coal still supplies close to 55 percent of China’s electricity generation, that electricity remains relatively carbon-intensive compared with the U.S. grid. China’s rapid urbanization has compounded this effect: hundreds of millions of people have moved from rural areas to cities since the 1990s, driving enormous demand for construction materials, transportation infrastructure, and residential energy use.

At the same time, China’s economic model has begun to shift. Government planning documents, including the country’s recent Five-Year Plans, have placed growing emphasis on “high-quality growth,” domestic consumption, and leadership in advanced manufacturing sectors such as electric vehicles, batteries, and renewable energy equipment. China is both the largest manufacturer of solar panels and wind turbines in the world and one of the largest consumers of coal, which reflects an economy in transition rather than one committed permanently to either a high-carbon or low-carbon path.

2.3 Comparing the Two Structures

Table A below summarizes some of the key structural differences between the two economies that help explain their divergent emissions trends.

Table A. Structural Comparison of the U.S. and Chinese Economies (approximate, 2023–2024)

Indicator	United States	China
Services share of GDP	~80%	~55%
Industry share of GDP	~18%	~38%
Agriculture share of GDP	~1%	~7%
Coal share of electricity generation	~16%	~55%
Urban population share	~83%	~65%
Net energy trade position	Net exporter	Net importer

These figures help explain much of what appears later in this paper’s statistical analysis. A service-heavy, energy-independent economy such as the United States can grow its GDP without proportionally increasing its energy consumption or emissions, since much of that growth comes from sectors—software, finance, healthcare—that are not energy-intensive. An industry-heavy, urbanizing, and energy-importing

economy such as China, by contrast, tends to see emissions rise in step with GDP, since a large share of its growth still comes from energy-intensive construction and manufacturing. This structural contrast is the underlying economic story behind the statistical relationships explored in Sections 4 and 5, and it is important to keep in mind that the correlation and regression results presented later are, in large part, a numerical reflection of these deeper structural differences rather than a coincidence of timing.

It is also worth noting that these structures are not fixed. China's stated ambition to grow its service sector and reduce its reliance on heavy industry, if realized, would be expected to weaken the historically strong positive relationship between GDP growth and emissions documented in this study. Conversely, any reversal of the U.S. shift toward services and energy independence—for example, a renewed expansion of heavy industry—could weaken the negative relationship observed in the U.S. data. The structural comparison offered in this section should therefore be read as a snapshot of the current relationship between economic structure and emissions, not a permanent law of either economy.

2.4 Historical Growth Trajectories in Context

It is useful to place the 1990–2024 window examined in this paper within a longer historical perspective. The United States had already completed most of its industrial expansion by 1990, having built the core of its manufacturing base, highway system, and electricity grid over the preceding century. Its GDP growth since 1990 has therefore come mainly from productivity gains, technological innovation—particularly in information technology and, more recently, software and digital services—and the ongoing expansion of the service sector, rather than from the construction of entirely new industrial capacity. This matters for interpreting the emissions data: much of the infrastructure responsible for U.S. emissions, such as power plants and highway networks, was already built before the study period began, so the emissions reductions documented in Section 4 come mostly from retiring or replacing existing high-carbon infrastructure (older coal plants, for example) rather than from avoiding the construction of new infrastructure in the first place.

China's situation in 1990 was fundamentally different. At that point, only a little more than a decade had passed since the start of market reforms, and the country's infrastructure, housing stock, and industrial base were still comparatively undeveloped relative to its population. The GDP growth China has experienced since 1990 therefore reflects, in large part, the physical construction of an entire modern economy: cities, factories, highways, ports, and power plants that did not previously exist at anything like their current scale. This helps explain why China's growth has been so closely tied to emissions in a way that U.S. growth has not been over the same period—a large share of Chinese GDP growth has literally consisted of building new energy-consuming physical capital, whereas a large share of U.S. GDP growth over the same decades has consisted of using already-built capital more productively, or expanding sectors that require comparatively little physical infrastructure at all.

This distinction is not meant to suggest that China's growth path was avoidable or illegitimate—every currently wealthy country, including the United States, went through a similarly energy-intensive phase of infrastructure construction during its own industrialization, simply earlier in history and before global climate change had become a widely recognized concern. It does suggest, however, that comparing the two countries' emissions trajectories requires some care: China is, in some respects, passing through a phase of development that the United States passed through in earlier decades, under a very different set of environmental constraints and technological options than exist today.

3. Method

3.1 Data Sources

Seven open data sets were used in this study, all of which can be downloaded free of charge.

Table 1. Data Sets Used

Data Set	Provider	Coverage
GDP (current US\$)	World Bank	1990–2024
Population	World Bank	1990–2024
Renewable energy consumption (%)	World Bank / IEA	1990–2023
CO ₂ emissions (Mt)	EDGAR / Global Carbon Project	1990–2023
GDP per capita	IMF / World Bank	1990–2024
Electricity generation	IEA	2020–2023
Energy consumption	EIA / IEA	1990–2023

3.2 Analytical Methods

All data processing and visualization were carried out in Microsoft Excel, following these steps:

1. **Descriptive statistics:** percentage change, mean, and standard deviation were calculated using Excel formulas.
2. **Trend analysis:** year-by-year values were plotted as line charts, with a linear trendline added using Excel's built-in trendline feature.
3. **Correlation analysis:** the direction and strength of the relationship between two variables were calculated using Excel's `=PEARSON()` (or `=CORREL()`) function. The Pearson correlation coefficient (r) ranges from -1 to $+1$; values above ± 0.70 were treated as a strong relationship, and values above ± 0.90 as a very strong one.
4. **Simple linear regression:** the relationship between a single independent variable (X) and a single dependent variable (Y) was modeled using Excel's trendline equation, in the form $Y = aX + b$, where a is the slope and b is the intercept. The R^2 value indicates the share of variation in the data explained by the line, expressed as a percentage.

Note: This study examines only pairwise relationships between two variables at a time. More advanced techniques such as multiple regression, which considers three or more variables simultaneously, fall outside the scope of a high-school-level project and were not used.

3.3 Data Reliability and Handling

Several practical steps were taken to keep the analysis as reliable as possible given the constraints of a high-school project. First, wherever a data set offered more than one plausible source—for example, both the World Bank and the IEA publish renewable energy shares, sometimes with small differences in methodology—the source with more complete year-by-year coverage over the full 1990–2024 period was preferred, and the choice was kept consistent throughout the analysis rather than switching sources from

year to year. Second, monetary figures such as GDP are reported in current (nominal) U.S. dollars rather than inflation-adjusted terms, which is standard practice for the data sets used here but means that part of the reported GDP growth, particularly for the United States, reflects general price inflation rather than growth in real output. This does not affect the correlation or regression results, which are based on the trend and direction of the relationship rather than absolute dollar values, but it is a relevant caveat when interpreting the percentage changes reported in Table 2.

Third, where a small number of individual data points were missing—typically the most recent year for a slower-updating data set such as EDGAR’s CO₂ figures—linear interpolation between the nearest available years was used rather than dropping the year entirely, since dropping years would have created gaps in the trendlines and made the regression less reliable. Fewer than five data points across the entire study required this treatment. Finally, all raw data downloads, the Excel workbook containing the calculations, and the resulting charts were kept together in a single file so that every reported number in this paper could be traced back to its original source and formula, a practice recommended by the supervising teacher for this kind of independent research project.

4. Findings

4.1 Economic Growth, 1990–2024

Between 1990 and 2024, U.S. GDP rose from \$5.96 trillion to \$28.78 trillion, an increase of about 383 percent, with temporary contractions during the 2008 global financial crisis and the 2020 COVID-19 downturn.

Over the same period, China’s GDP grew from \$0.39 trillion to \$18.27 trillion—an increase of roughly 4,586 percent—making it the fastest-growing major economy in the world. Growth accelerated markedly after China joined the World Trade Organization in 2001, and by 2010 the country had become the world’s second-largest economy.

4.2 CO₂ Emissions

U.S. emissions stood at 6,209 Mt in 1990, peaked at roughly 7,200 Mt in 2005, and had fallen to about 4,850 Mt by 2024—a decline of approximately 32.6 percent from the 2005 peak.

China’s emissions, by contrast, rose from 3,876 Mt in 1990 to overtake the United States as the world’s largest emitter by 2005, reaching about 12,600 Mt in 2024. This represents roughly a threefold increase since 1990, although the annual growth rate has slowed to below 1 percent since 2020.

4.3 Per Capita CO₂ Emissions

Per capita emissions in the United States fell from 24.8 tons in 1990 to 14.4 tons in 2024. In China, the figure rose over the same period from 3.4 tons to 8.9 tons. The United States still emits about 1.6 times more per person than China does, though this gap has narrowed considerably from the 7.3-fold difference recorded in 1990.

4.4 Renewable Energy Consumption

The renewable energy share of U.S. consumption rose from 6.1 percent in 1990 to approximately 12.5 percent in 2024, with the increase accelerating after 2005 as investment in solar and wind expanded.

China's renewable share appears high at the start of the period—around 25.0 percent in 1990—but most of this reflected traditional biomass sources such as wood and animal dung rather than modern renewables. As the country shifted toward modern sources (solar, wind, hydropower), this share actually fell to 15.2 percent by 2005 before climbing back to about 17.5 percent by 2024 as modern renewable capacity expanded.

4.5 Carbon Intensity

Carbon intensity—CO₂ emitted per dollar of GDP (kg CO₂/US\$)—reflects how “clean” a country's economic growth has been. In the United States, this figure fell from 1.04 kg/\$ in 1990 to 0.17 kg/\$ in 2024, a decline of about 84 percent. In China, the equivalent figure fell from 9.9 kg/\$ in 1990 to 0.69 kg/\$ in 2024, a decline of about 93 percent. Despite remaining the world's largest manufacturing base, China has made substantial progress in this area through gains in energy efficiency and renewable investment.

4.6 Summary of Key Indicators

Table 2. Key Indicators for the United States and China (1990 and 2024)

Indicator	United States			China		
	1990	2024	Change	1990	2024	Change
GDP (US\$ trillion)	5.96	28.78	+383%	0.39	18.27	+4,586%
CO ₂ (Mt)	6,209	4,850	−22%	3,876	12,600	+225%
Per capita CO ₂ (t)	24.8	14.4	−42%	3.4	8.9	+162%
Renewables (%)	6.1	12.5	+105%	25.0*	17.5	−30%*
Carbon intensity (kg/\$)	1.04	0.17	−84%	9.9	0.69	−93%
GDP per capita (\$)	23,850	86,000	+261%	345	12,800	+3,612%

*Note: The negative change in China's renewable share reflects the shift away from traditional biomass toward modern energy sources.

4.7 Electricity Generation Mix

Because electricity generation is one of the largest single sources of CO₂ emissions in both countries, it is worth examining separately from the aggregate figures presented above. Using IEA data for 2020–2023, coal accounted for roughly 16 percent of U.S. electricity generation on average over this period, down from over 50 percent as recently as 2005, with natural gas (around 40 percent), nuclear (around 19 percent), and a combination of renewables—chiefly wind, solar, and hydropower—making up most of the remainder, at close to 22 percent combined.

China's electricity mix over the same 2020–2023 period remained far more coal-dependent, with coal supplying approximately 55–60 percent of generation, even as the country simultaneously built out the largest wind and solar fleet in the world. Hydropower contributes a meaningful share of Chinese generation, at around 15 percent, reflecting decades of large-scale dam construction, while nuclear remains a comparatively small share of the mix relative to countries such as France or the United States. This combination—a still-dominant but slowly shrinking role for coal alongside the world's fastest-growing renewable capacity—captures the central tension in China's current energy transition: total renewable capacity additions are enormous in absolute terms, but they have so far been used mainly to meet growing electricity demand rather than to displace existing coal capacity outright, which is part of why China's emissions had not yet peaked as of the most recent data used in this study.

This generation-mix comparison reinforces the carbon intensity findings in Section 4.5: an electricity grid that is only 16 percent coal-fired, as in the United States, produces far fewer emissions per unit of electricity than one that remains 55 percent coal-fired, as in China, even before accounting for differences in industrial structure discussed in Section 2. Closing this gap in the power sector is likely to be one of the single most consequential levers available to Chinese policymakers seeking to bend the country's emissions trajectory toward an earlier peak.

5. Statistical Analysis

5.1 Correlation Analysis

Correlation coefficients, calculated in Excel using the =PEARSON () function, are summarized below.

Table 3. Pearson Correlation Coefficients

Relationship	United States (<i>r</i>)	China (<i>r</i>)
GDP ↔ CO ₂	−0.78	+0.96
Renewables ↔ CO ₂	−0.88	−0.71
GDP ↔ Renewables	+0.97	−0.49

Interpretation:

- In the United States, GDP and CO₂ emissions are strongly and negatively correlated: as the economy grows, emissions tend to fall.
- In China, the same relationship is strongly positive: emissions rise as the economy grows.
- In both countries, a higher renewable energy share is associated with lower CO₂ emissions.
- In the United States, economic growth and renewable energy use rise together, whereas in China the two are weakly and negatively correlated—largely because China's high “renewable” share in 1990 mainly reflected traditional wood-burning rather than modern clean energy.

5.2 Simple Linear Regression

Trendline equations were fitted separately for each independent variable in Excel, with the following results:

United States:

$$\text{CO}_2 = 7,627 - 101 \times \text{GDP} \quad (R^2 = 0.61; \text{the model explains 61\% of the variation})$$

$$\text{CO}_2 = 9,049 - 366 \times \text{Renewables} \quad (R^2 = 0.77; \text{the model explains 77\% of the variation})$$

China:

$$\text{CO}_2 = 5,041 + 464 \times \text{GDP} \quad (R^2 = 0.92; \text{the model explains 92\% of the variation})$$

$$\text{CO}_2 = 17,776 - 570 \times \text{Renewables} \quad (R^2 = 0.51; \text{the model explains 51\% of the variation})$$

Interpretation: The GDP coefficient for the United States is negative (-101), meaning that emissions fall by an estimated 101 Mt for every additional \$1 trillion of GDP. For China, the coefficient is positive ($+464$): emissions rise by an estimated 464 Mt for every additional \$1 trillion of GDP.

Important caveat: these equations capture only the relationship between two variables at a time. In practice, emissions are shaped by many additional factors—population, industrial structure, and technological change among them—so GDP or renewable energy share alone cannot fully account for changes in emissions.

6. Discussion

6.1 The United States: Technological Change and Falling Emissions

The main driver behind the decline in U.S. emissions has been the shale gas boom that followed 2008. Rising shale gas production made natural gas cheaper than coal and considerably less polluting, accelerating its adoption in electricity generation. According to the U.S. Energy Information Administration, coal's share of total energy consumption fell from 37 percent in 1950 to about 9 percent in 2024, and a large share of that decline has occurred since 2008 specifically, as utilities retired aging coal plants that could no longer compete on price with natural gas.

Even so, U.S. per capita emissions (14.4 tons) remain roughly three times the global average of about 4.8 tons, which points to how much room for further reduction still exists even after three decades of relative progress. Clean-energy investment under the Inflation Reduction Act, which took effect in 2022, drove record growth in solar and wind capacity in 2023 and 2024, along with a rapid expansion of domestic battery and electric vehicle manufacturing intended to reduce reliance on imported clean-energy components. Whether this investment continues at the same pace will depend heavily on future federal policy, a point returned to in Section 6.3 below.

6.2 China: Rapid Growth and a Renewable Energy Push

The rise in China's emissions is rooted in its export-driven industrial expansion since 2001, discussed in more structural detail in Section 2.2. China leads the world in energy-intensive sectors such as steel, cement, and aluminum production, and a substantial share of that output is exported rather than consumed domestically, which connects back to the consumption-based accounting issue raised in Section 6.6.

At the same time, China has made striking gains in renewable energy over the past decade: as of 2024, more than 40 percent of the world's solar capacity is located in China, and the country has also become the leading global manufacturer of the panels, turbines, and batteries used in renewable energy systems worldwide, including many installed outside China. The Chinese government has set a target for emissions to peak by 2030, and provincial-level data suggests that some of China's wealthier, more service-oriented coastal provinces may already be approaching a peak individually, even while less-developed inland provinces continue to industrialize and increase their emissions—a reminder that the national totals used throughout this paper mask considerable regional variation within China.

6.3 Key Differences Between the Two Countries

- **Stage of development:** the United States has shifted toward a service-based economy, while China's economy remains weighted toward industry and construction, for the historical reasons discussed in Section 2.4.

- **Energy independence:** the United States has moved close to energy self-sufficiency and become a net oil exporter, while China remains dependent on energy imports, which has pushed it toward domestic renewable sources partly as a matter of energy security rather than climate policy alone.
- **Policy stability:** U.S. federal energy policy can shift substantially from one administration to the next—clean energy tax credits, fuel economy standards, and international climate commitments have all been expanded and then rolled back at various points over the study period—while China’s centralized planning system makes it easier to sustain long-term climate targets across multiple Five-Year Plans, even though it offers fewer opportunities for public input into how those targets are set.
- **Population and scale:** China’s population, at over four times that of the United States, means that even a modest per capita emissions figure translates into a very large absolute national total; conversely, the comparatively small U.S. population combined with a high per capita figure produces a national total that, while smaller than China’s, remains far above the global per capita average discussed in Section 6.1.

Taken together, these differences suggest that the two countries are unlikely to converge on identical emissions trajectories in the near future, even under similarly ambitious policy commitments. Progress in the United States is likely to continue depending heavily on the pace of the ongoing shift away from coal and toward renewables and natural gas within the electricity sector, while progress in China is likely to depend more on the extent to which its stated shift toward services and “high-quality growth” actually materializes in the industrial data over the coming decade.

6.4 The Role of Renewable Energy in Reducing Emissions

A negative relationship between renewable energy share and CO₂ emissions was found in both countries. In the United States, emissions fell from 7,200 Mt to 4,850 Mt as the renewable share rose from about 6 percent to 12.5 percent. In China, the growth of renewable energy has slowed the rate of increase in emissions, though it has not yet produced an absolute decline.

This contrast reflects the different stages of development the two countries are in. In a high-income economy like the United States, emissions can fall even as the economy continues to grow; in a middle-income, rapidly industrializing economy like China, emissions are still rising, albeit at a slower pace relative to GDP growth.

6.5 Limitations of the Study

As a high-school project, this study has several limitations:

- **No test of causation was performed.** Correlation shows that two variables move together, but it does not establish that one causes the other. In the U.S. case, for instance, the shale gas boom, efficiency gains, and the offshoring of industry likely all contributed to falling emissions alongside GDP growth.
- **Only two variables were examined at a time.** More advanced techniques taught at the university level, such as multiple regression and panel data analysis, were not applied here, so the models cannot fully account for changes in emissions (R^2 reaches at most 0.77 for the United States and 0.92 for China).

- **2024 data limitations:** final, confirmed figures for 2024—particularly CO₂ data from EDGAR—may not yet be available for some data sets, so the most recent year’s values are based on preliminary institutional estimates.

6.6 Trade and the Question of Consumption-Based Emissions

One issue raised in the literature review deserves further attention here: the difference between production-based and consumption-based emissions accounting. All of the emissions figures used in this study, in line with standard practice, are production-based—they count emissions where goods are manufactured, not where those goods are eventually sold or used. Because China manufactures a large share of the world’s consumer electronics, clothing, furniture, and industrial equipment, a meaningful portion of the emissions attributed to China in this paper are generated in the process of making goods that are ultimately shipped to and consumed in the United States, the European Union, and elsewhere.

Studies using consumption-based accounting—which reallocate emissions to the country where a good is finally consumed rather than produced—generally find that this adjustment narrows the emissions gap between the United States and China somewhat, since it shifts some emissions currently counted under China back onto the countries that import Chinese-made goods. It does not reverse the overall picture; China’s consumption-based emissions are still substantial given the size of its population and its own rapidly growing domestic consumption, but the adjustment is large enough that it should be kept in mind whenever emissions figures are used to assign moral or political responsibility for climate change between countries. This paper does not attempt its own consumption-based recalculation, as the underlying trade-flow data required is considerably more complex than the production-based figures used elsewhere in this study, but flags the issue as an important limitation of the analysis presented in Sections 4 and 5.

6.7 Outlook to 2030

Both governments have published forward-looking targets that provide a useful benchmark against which to judge the trends documented in this paper. The United States has committed, under its Nationally Determined Contribution to the Paris Agreement, to reducing emissions by around 50–52 percent below 2005 levels by 2030. Given that emissions had fallen by about 32.6 percent from the 2005 peak as of 2024, meeting this target would require the pace of annual reductions to accelerate substantially over the remainder of the decade, a pace not yet reflected in the historical trend used for the regression in Section 5.

China’s official position is that emissions will peak before 2030 and that the country will achieve carbon neutrality by 2060. Because Chinese emissions were still rising as of 2024, though at a slower annual rate than in the 2000s and early 2010s, the coming years will be a critical test of whether this peak occurs on schedule. Some independent energy analysts have suggested that China’s emissions may already be close to a plateau, driven by record additions of solar and wind capacity and slower growth in energy-intensive construction, though this had not been confirmed in the data available at the time this paper was written. If confirmed in later data, an early peak would represent a meaningful shift in the GDP-emissions relationship documented in Section 5, since it would imply that Chinese growth is beginning to decouple from emissions in a way it has not done historically.

7. Conclusion and Recommendations

Key Findings

- **Different stages of development:** the United States shows an inverse relationship between economic growth and CO₂ emissions, with emissions falling as the economy expands. China has not yet reached this stage.
- **Effect of renewable energy:** in both countries, rising renewable energy use is associated with lower carbon intensity—emissions per unit of GDP.
- **China's leadership in capacity:** China holds the world's largest renewable energy capacity, but its total emissions have not yet peaked.
- **Per capita gap:** the United States still emits far more per person than China does.

Recommendations

Based on the findings above, the following recommendations follow, presented in more detail than a simple list in order to connect each one back to the specific evidence that motivates it.

1. **Education and awareness:** school curricula should devote greater attention to climate change and renewable energy, including basic data literacy of the kind used in this project. Many of the patterns described in this paper—decoupling, carbon intensity, correlation versus causation—are not difficult concepts, but they are rarely taught before university, even though they are essential for understanding one of the defining issues of this generation.
2. **Technology transfer:** developed countries, and the United States in particular, should accelerate the transfer of clean energy technologies to developing economies. Since much of the cost of solar and wind technology has already been paid down through decades of research and deployment in wealthier countries, sharing this technology—and the manufacturing know-how behind it—could allow industrializing economies to build cleaner infrastructure from the outset rather than replicating the high-carbon development path historical industrializers followed.
3. **Carbon pricing:** emissions trading systems and carbon taxes can help reduce emissions through market mechanisms by making high-carbon activities more expensive relative to cleaner alternatives, without requiring governments to pick specific technologies as winners. The European Union's emissions trading system and various U.S. state-level carbon markets offer working examples, though neither the United States nor China currently prices carbon at the national level in a comprehensive way.
4. **Continued investment in grid-scale renewables and storage:** given that renewable energy share was the strongest single predictor of lower emissions in the U.S. data ($R^2 = 0.77$) and a meaningful predictor in the Chinese data as well, continued investment in solar, wind, and the storage technology needed to integrate them reliably into the grid appears to be one of the most direct levers available to both countries.
5. **Youth movements and public engagement:** youth climate movements such as Fridays for Future can build public pressure that encourages the adoption of more ambitious climate targets. Public

opinion research suggests climate policy is more durable across changes in government when it enjoys broad public support rather than resting on the preferences of a single administration—a point of particular relevance given the policy instability noted in Section 6.3 with respect to the United States.

Reflections on the Research Process

Working on this project over the course of the year taught me as much about the process of research as about the subject matter itself. Reconciling data from different sources—the World Bank, the IEA, and EDGAR do not always agree exactly on a given year's figures, since they use slightly different methodologies and revision schedules—was more time-consuming than I expected, and it gave me a much better appreciation for why researchers are usually careful to specify exactly which data set and vintage a claim is based on. Learning to distinguish correlation from causation was also a recurring challenge: it was tempting, especially early on, to describe the strong statistical relationships in Section 5 as if they proved that GDP growth causes emissions, or that renewable energy causes emissions to fall, when in fact the data only show that these variables move together, for reasons that likely include the structural factors discussed in Section 2 as well as many others not captured in this analysis.

If I were to extend this project further, I would be interested in incorporating consumption-based emissions data, as discussed in Section 6.6, and in extending the analysis to other large emitters such as India and the European Union to see whether the patterns found here for the United States and China—a strong negative GDP-emissions correlation in a mature, service-based economy and a strong positive correlation in a rapidly industrializing one—hold more generally, or whether the U.S. and China are unusual cases in some way. I would also like to revisit this analysis in a few years, once 2025–2030 data becomes available, to see whether either country's emissions trajectory moves closer to its stated 2030 targets.

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Conflicts of Interest

The author declares that there are no conflicts of interest related to this work.

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