Green Energy Transition

Does Economic Growth Drive Transition to Renewable Energy?

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ABSTRACT

This study examines how GDP relates to renewable energy produced across countries using data from the World Bank and Our World in Data. We analyze three indicators: renewable electricity production, the share of renewables in total energy consumption, and CO_2 emissions.

We find that renewable energy production increases with economic size, accelerating at higher GDP levels. However, this expansion does not immediately translate into a higher renewable share. Instead, the share of renewables declines across much of the development process and increases only in the highest-income economies. A similar pattern is observed for CO_2 emissions, which rise with GDP and start to fall only at very high income levels.

KEYWORDS

Renewable energy, GDP, Energy transition, CO_2 emissions, U-shaped relationship

1 Introduction

Climate change is one of the biggest risks that humanity currently faces. It affects the modern world with more frequent natural disasters like floods, hurricanes and wildfires threatening the lives and living places of millions of people. The current global economy relies on burning fossil fuels for energy production, which emits huge amounts of CO_2, contributing to the intensification of climate change. With the digitalization of society and its increase of energy demand, the transition from fossil fuels to renewable energies is evident and urgent.

Through the Paris Agreement in 2015, this issue was recognized by nearly all of the economies of the world, which, through this agreement, have set a commitment for reducing the global temperature. Greenhouse gas emissions have been found to be the biggest contributors to the increase in global temperature. Since one of the biggest industries contributing to these emissions is the energy industry it is evident that in order to reduce greenhouse gas emissions there has to be a transition to green energy. Thus it is expectable that countries must incentivize the production and consumption of renewable energy.

2 Motivation

Our motivation was to investigate if due to the commitment of the green energy transition, the economic drive of a given country is invested in renewable energy development. The main question was if the economic growth of a country reflects their commitment to invest in renewable energy. Does the conclusion depend on the metric chosen?

There are many ways and angles to analyze this issue, in this case we needed to focus on two specific measurable indicators. We wanted to explore the relation between a country's increase in financial resources and its increase in renewable energy development.

3 Data-driven process

3.1 Data

We needed to find metrics that were a good representation of the aforementioned relation, for this we explored some indicators.

For the financial resource increase indicator, we choose annual Gross Domestic Product (GDP), measured taking inflation into account. GDP is a widely accepted measure of how well a country's economy is performing. It includes the total monetary value of all final goods and services produced within a country's borders (United Nations, 2009) in a specific time period, year in this study. GDP rather than GDP per capita is used here since the former is a more relevant metric when measuring scale and wealth in a country with the idea that in order to produce energy using hydroelectric plants big investment is needed.

For the renewable energy development metric, we tested with three indicators.

The first indicator used was the annual Absolute Renewable Electricity Generation by country, measured in TWh for each source (wind, hydro, solar and other renewables including bioenergy, geothermal, wave, and tidal energy). This metric represents the total volume of electricity, in TWh, produced by renewable power plants in a specific country over the course of one year. This data was retrieved in Our World in Data and collected by Ember Energy with major processing by Our World in Data (Energy Institute & Ember, 2026).

The second indicator tested was the annual Share of Renewable Energy Consumption [REC] by country, as a percentage of total final energy production. This metric represents the proportion of renewable energy, in percentage, produced annually in a given country. This data was retrieved through the DataBank of the World Bank Group (World Bank Group, 2026b).

As a third, complementary indicator, CO_2 emissions are also used. These refer to the territorial based emissions that a given country produces when burning fossil fuels for electricity, transport, heating and industrial processes. Retrieved from the Our World in Data platform (Our World in Data, 2026).

We choose this last metric with the expectation that these start falling when the share of renewables starts rising or slightly afterwards.

All the aforementioned data was retrieved between 1990 until 2022 and was collected by country globally.

Previous studies in this field indicate that the GDP and share of REC have a U-shaped relation, meaning that the share of renewables often falls with growing GDP initially, but tends to increase as the GDP increases later on. This is often referred to as the Renewable Kuznets Curve (RKC), named after Nobel Prize Laureate Simon Kuznets. After having reached high GDP, however, further GDP-growth often leads to rising share of REC (Khan & Hou, 2023). With that in mind the choice of metric regarding economic growth is absolute GDP rather than the annual increase of it.

3.2 Methods

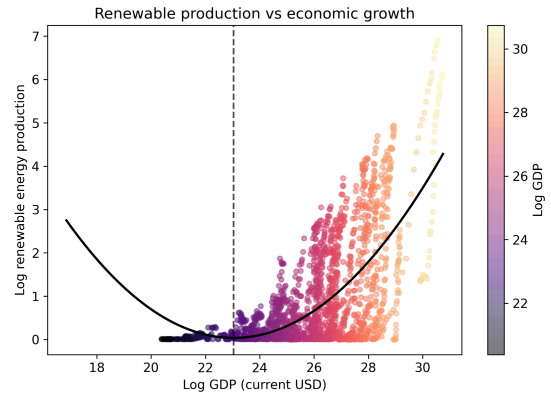
The approach applied here is pooled analytics, meaning that development in individual countries over time has not been taken into account. This is done mainly because using data for several countries and doing that with timeseries would have been challenging to visualize. The pooled method also means a bigger dataset.

Bivariate analysis has been performed on GDP related to production of renewable energy in TWH, share of renewable energy out of total energy produced and CO_2 emissions. The aim of this method is to show how risky it can be to draw conclusions on one metric alone.

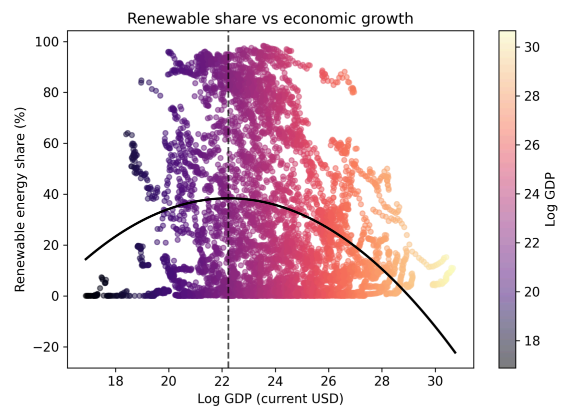
All features except percentages have been transformed using a logarithmic function in order to increase readability as data is skewed.

4 Results

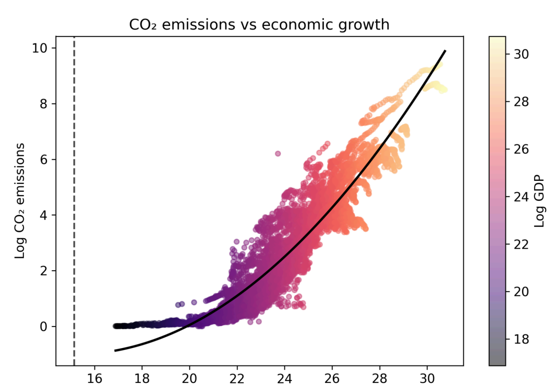
The graph below shows that production of energy using renewable sources increases with GDP. Since we are dealing with absolute numbers here, not related to total production, this is expected. Important here is rather that the slope of the curve tends to be more steep with higher GDP. The trendline indicates a U-shaped curve. This is because at an early stage in the development of a country energy created by burning firewood is replaced by coal. The former is treated as renewable while the latter is not, hence the early decrease.



Below we can see that the share of REC declines throughout most of the increase of GDP. At the very end we see a possible change in trend when GDP is high, the REC share starts to slightly increase again, but only at very high levels as is shown on the far right below. High GDP can be interpreted as an enabler for transition to clean energy rather than an immediate cause.



The graph below shows that as a country's GDP grows so does their CO_2 emissions, except, again that at very high levels of GDP, where CO_2 emissions start to decrease.



In the table below we can see relevant metrics for the relation between log GDP and the three variables presented in the former graphs. Although quadratic terms improve model fit in all cases ($p < 0.001$), the relative importance of nonlinearity differs substantially. For renewable energy share in production, the coefficient of determination almost doubles, indicating a strongly threshold-driven relationship, albeit from a very low level of correlation.

Variable	R2 linear	R2 quadratic	Delta_R2 absolute	Delta_R2 relative
Renewable production	0.339	0.431	0.091	26.9
Renewable share	0.045	0.087	0.042	93.3
CO2 emissions	0.853	0.881	0.028	3.3

The model comparison using AIC (Akaike Information Criterion), as shown below, strongly favors the quadratic specification over the linear one for all three indicators. The difference exceeds 280 in all cases, indicating that the relationship between GDP and all three dependent variables is mainly nonlinear. The extremely low p-value from the F-test further confirms this statement.

Variable	AIC linear	AIC quadratic	F-test p-value
Renewable production	5813.1	5513.5	0.0
Renewable share	61863.3	61576	0.0
CO2 emissions	15897.3	14444.8	0.0

We have seen that production of energy using renewable sources initially decreases and later increases when measured in absolute numbers. However, when looking at CO_2 and share of renewables in consumption this transition occurs only at much higher levels of GDP. We can say that GDP matters, that its effect is mainly non-linear and also that GDP alone only explains part of the variance, especially regarding share of renewable energy produced.

5 Discussion

Previous studies reveal a divergence in findings when it comes to identifying the causal relationship between renewable energy and economic growth. The results depend heavily on the region or countries selected for the study, the timeframe that is analyzed, the type of test that is performed to inspect the causal relation and the indicators that are taken into consideration as well. (Raifu et al., 2025) For example, He and Huang (2022) reveal a bidirectional causality between renewable energy and economic growth. The study, which focuses on China, also reveals that economic growth is positively affected by REC. While other studies point at a negative relationship, like Ocal and Aslan (2022) which found unidirectional causality from economic growth to REC. Among many other studies that arrived at divergent conclusions, thus no consensus has been reached from the scientific community on the core of this causal relationship. (Raifu et al., 2025) Our analysis follows a similar trend, we were not able to find a strong linear or nonlinear relation for the variables explored.

Overall our results were surprising to us. Prior to the relevant literature review, we were expecting to see a clear positive increase in REC share as GDP grew, but our results were slightly different. They slightly reflect what the RKC suggests, that while early economic development often requires an investment in non-renewable sources, therefore a decrease in REC share, after a certain wealth threshold, there is a turning point where the REC share starts to increase as GDP grows (Mahmood et al., 2023). Thus the negative quadratic relation between GPD and REC share found in our results, even though with a weak explainability score, are congruent with this theory.

5.1 Ethical Reflection

A critical reflection to be considered is the environmental impact of the manufacturing of renewable energy systems and the energy sources that are included in this category.

Now we may argue that the initial investment in the development of renewables can negatively impact the environment by how much resources they initially require to be fabricated. These have a heavy reliance on critical minerals whose extraction is associated with high water use, solid degradation, and chemical pollution, by which we are of the opinion that these extraction methods should be revised to be more sustainable. Despite these high initial manufacturing costs, the total life-cycle emissions for renewables are still small compared with the direct emissions of non renewable power plants, and in the long term less damaging to the environment. (Hertwich et al., 2015).

It is also worth mentioning that while coal burning is considered non-renewable, biomass energy, which in most cases is accomplished by burning harvested wood from forests, is considered renewable. In this study the indicators for renewables used included wind, hydro, solar, geothermal, wave, tidal, and biomass energy. In the opinion of the authors this last way of producing energy should be considered non-renewable. Since the carbon debt from continuous harvesting of trees often exceeds the rate of forest growth, assuming the land remains a forest, studies show that it can take from 44 to 104 years to replenish this carbon emissions. (Sterman et al., 2018)

Another relevant ethical concern to be mentioned is the potential narrative fabrication according to which metric is used.

A narrative influenced by political interests could possibly support the claim that globally, or a given country is increasing its renewable energy production, but this is not so relevant if its share REC is not increased. However, since the global energy demand is growing faster than the renewable deployment, the share of renewables in the total mix may remain stagnant or even actually decrease. But a clean, reliable energy future is possible, if countries can invest properly in its development. (Li et al., 2025)

5.2 Societal impact

On a societal level, the RKC is highly relevant, as previously mentioned, the initial economic growth of a country may demand the use of fossil fuels, which would damage the environment, and only in later stages, as the population needs for clean atmosphere increase, there are naturally increasing demands to shift towards renewable energy sources. (Mahmood et al., 2023)

An important consideration is that, even though the World Scientists' Warning to Humanity was first written in 1992 about the possible irreversible damage on the environment from human activities, (Union of Concerned Scientists, 1992) it was only in 2015 that through the Paris Agreement, most of the world's nations assumed the responsibility of mitigating climate change. Although some nations had independently taken the initiative to mitigate their own impact, it is plausible that accountability can only be established after the year 2015, for which limited data is available.

As mentioned above, and shown in this study, the metrics that are used when analyzing transition to renewable energy affect what conclusions can be drawn. Research done related to energy production in general and transition to renewables in particular can have a political impact and may in turn also be affected by different political and also economical interests. It is important to keep this in mind when reading reports dealing with these issues.

6 Future work

In this study GDP alone has been used to explain variables relevant when measuring transition to clean energy. This choice was done as this relation has been handled in several papers clearly stating the importance of GDP in this context. Features regarding the labor force, real capital, level of democracy, demographic data and also to what extent geography enables production of clean energy are possible additional variables that could have an effect on the transition to production of clean energy.

Focusing more on the phase during which transition starts to take place in terms of increased share of renewables could also provide more insight as to what drivers are relevant. Here only bivariate analyses were performed since the purpose was to show that different conclusions can be drawn depending on what metric you choose. A multivariate approach that takes into account that the relation between dependent and independent variables differs with level of GDP, like histogram based regression, could provide a better picture of the relation.

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