Comparative Analysis of Human Development and Renewable Energy Policies: A Cross-Sectional & Longitudinal Analysis

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Abstract:

We explore the relationship between a country's Human Development Index (HDI) and the adoption of renewable energy. Employing different methods, we analyzed renewable energy policies in five countries: China, India, Germany, the US, and South Africa. Then, we quantified the HDI and the share of modern renewable energy percentage data from these countries. Additionally, we included cross-sectional and longitudinal analyses. The findings from the latter reveal a strong correlation between HDI growth and renewable energy expansion within a country over time, confirming the hypothesis that advances in a country's HDI over time result in greater renewable energy consumption. Although developed countries exhibit higher levels of renewable energy, investment, and subsidies, targeting rights-focused policies like technology education can improve green energy composition. We highlight how HDI growth alone is insufficient to expand a country's renewable energy sources, as integrated development and sustainable energy strategies tailored to the country are necessary.

Key words: Public Policy, Climate Policy, Environmental Economics, Econometrics, Data Analysis

Introduction:

In recent years, the global energy landscape has undergone major changes in many countries. From 2000 to 2023, global renewable energy capacity increased by over 400%, with solar and wind power leading the charge (IEA, 2023). With renewable energy sources experiencing unprecedented growth due to falling costs and growing concerns about climate change, this paper explores the intricate relationship between a country's socio-economic development and its renewable energy transition.

There are two parts to this paper. The first part is a literature review containing descriptions of policies that have been established in many different countries that have helped drive their renewable energy output. By conducting a comparative analysis of developed and developing nations, this part of the study aims to understand how factors such as economic growth, technological advancement, and government policies shape the adoption of renewable energy technologies. The second part of the paper quantifies the relationship between socio-economic development and the percentage of total energy derived from renewable energy sources at the country level. We hypothesize that the more developed a country is, the greater its total energy that comes from renewable energy. To test this hypothesis, a cross-sectional and longitudinal analysis was conducted. The cross-sectional analysis examined the relationship between many countries in 2021. The longitudinal analysis examined the relationship within the 5 countries discussed in the literature review between 2000 and 2023.

Literature Review:

In-depth analysis of the policies established in these countries

China aims to become a global leader in renewable energy, driven by ambitious government policies and significant investments. The “Renewable Energy Law” is a framework policy attempting to foster the use of renewable energy sources across the country. This was established in 2005 and took effect in 2006. The law’s goals included increasing energy supply, improving China’s energy structure, all while protecting the environment and promoting sustainable development in the country. The Renewable Energy Law promotes the use of renewable energy sources such as wind, solar, water, biomass, geothermal, and ocean energy. Also, encourages the proportion of non-fossil energy consumption. The other flagship policy includes the Five-Year-Plan which is a series of innovation driven growth initiatives happening every 5 years, this development plan has ambitious targets of increasing the share of non-fossil fuels; expanding the number of installations of new solar, wind, and other renewable energy projects; and to implement new efficient energy sources across various sectors. One tariff that aligned with China’s goal of expanding their green energy sources was the Feed-in Tariffs (FiTs), these set of policies guarantee a fixed price for electricity that has been generated from

renewable energy sources, this allows for a stable and predictable stream of revenue for the producers of renewable energy making them more willing to keep producing.

India's key renewable energy policies focus on shifting their main energy source to come from renewable sources by 2030, aiming for 50% of the country's cumulative electric power to come from non-fossil fuels, including a target of 500 GW of non-fossil fuel-based capacity by 2030. The goal of this project is for India to move away from fossil fuels and focus more on green energy. The key policies that promote this goal are the RPO and the actions taken by the MNRE. The Ministry of New and Renewable Energy (MNRE) goals are to reduce carbon intensity and transition to clean energy across the power sector. Renewable Purchase Obligation (RPO) is a law that makes electricity distribution companies procure a certain percentage of their power from renewable sources. At the lower levels of the Indian government, various state-level schemes promote solar and wind power development, and the government provides financial incentives and subsidies to encourage investment in renewable energy projects. The National Solar Mission is India’s proposal of being a global leader in the production of solar power; the goal of this mission is to promote sustainable growth while addressing India’s energy security challenge. It will also constitute a major contribution to reducing the effects of climate change and carbon emissions in India. The Production Linked Incentive (PLI) is an example of this, this subsidy incentivizes domestic manufacturing of high-efficiency solar PV modules. Lastly, something to consider is that India is also exploring the potential of biomass as a renewable energy source through the National Bioenergy Program.

The most essential for green energy expansion in Germany is its policy called Germany's Energiewende, or energy transition. This is a comprehensive policy blueprint aimed at phasing out nuclear power and significantly increasing the share of renewable energy in the energy sector. Another strategy taken by the German government is the Renewable Energy Sources Act (EEG), which provides the legal foundation for the transition from nuclear energy to using sources of renewable energy, with Feed-in Tariffs to encourage the rapid growth of domestic green energy production, such as solar and wind power. The EEG also includes funds for research and development in renewable energy technologies.

In the United States, renewable energy policies are primarily driven by state-level initiatives instead of national-level policies, driving the expansion of renewable energy. Except for the "Renewable Portfolio Standard (RPS)," which mandates that requirements or goals for energy producers or providers to supply energy from low- or zero-carbon emission sources. These policies require or encourage energy suppliers to provide their customers with a stated minimum share of energy from eligible energy resources. To help further drive the growth each state sets its targets and goals, allowing for many differences in the adoption of green energy in the states across the U.S. At the federal level, the Investment Tax Credit (ITC) provides

significant tax incentives for investments in solar installations, among other renewable energy technologies, inspiring private energy companies to invest their money into renewable energy.

South Africa's primary renewable energy policy is the "Renewable Energy Independent Power Producer Procurement Program (REIPPPP)," which is a policy that has had significant reductions in tariff rates for solar photovoltaics (PV) and wind over a short period. Moreover, we want to mitigate the effects of climate change by adopting these policies. This target increased electricity generation through the investment in solar, wind, and other renewable energy sources by privately owned companies. This program facilitates private companies to develop renewable energy projects by providing them with access to the grid of the South African cities and allowing them to sell electricity to the national power utility without the government having to spend its provisions on this project. The REIPPPP is central to the country's transition away from coal dependency and towards a more diverse energy production, intending to reach 19 GW of renewable energy capacity by 2030. The South African government also utilizes the Integrated Resource Plan (IRP) to outline its long-term energy strategy, with a significant focus on integrating renewable energy sources like solar and wind power. The policy emphasizes public-private partnerships and utilizes a competitive bidding process to select the most cost-effective renewable energy projects. The government also provides financial incentives to encourage investment in renewable energy technologies.

Comparison between the policies established in these countries

In China, there is an added emphasis on developing the manufacturing capability compared to others; China focuses on increasing their number of domestic producers for key renewable energy technologies like solar panels, wind turbines, and batteries. This was possible through the “Made In China 2025”; their approach was through strong central government intervention to make this happen. Conversely, India takes a varied approach by combining both national-level policies (National Solar Mission, RPO) with state-level initiatives and external financial initiatives. India also has put a strong emphasis on the production of solar power through the foundation of the National Solar Mission initiative in their country, and they have a focus on addressing the lack of renewable energy sources in rural areas. Germany, on the other hand, has had a decentralized approach to this by asking citizens to go green on their own and providing initiatives like rooftop solar installations. However, Germany also has the Energiewende policy, which aims to decarbonize the energy sector, encompassing not just renewable energy but also energy efficiency measures and phasing out nuclear power. The United States, like Germany, has a decentralized approach to solving carbon emissions, which is by driving state-level subsidies like the RPS to push citizens to go green. The federal government has also implemented tax credits to incentivize citizens, this overall approach is much more fragmented than the methods used by China or India. South Africa’s unique approach to expanding its renewable energy sources is by working with other public and private organizations to persuade its citizens to adopt green energy. As talked about before, the

REIPPPP program facilitates private companies to bid for renewable energy projects, making it a mutually beneficial situation, since there will be substantial investments into sustainable sources, and the company will be able to make money in the process by dominating the market. This method attracts private investments to drive green energy expansion, while other countries rely on government initiatives and state-level policies.

Methods:

We investigate the relationship between country development status and energy investment in renewables, both cross-sectionally across countries and within countries over time. The cross-sectional analysis was performed on 132 countries in the year 2022. The within-country analysis was performed on China, India, South Africa, the United States, and Germany across 21 years from 2000 to 2021.

Data Collection:

Human development data for the cross-sectional analysis were gathered from the United Nations Development Programme (UNDP HDR, 2024). Additionally, we collected renewable energy data from the Energy Institute and OurWorldData (Energy Institute - Statistical Review of World Energy (2024) – with major processing by Our World in Data).

Gathered the HDI values for the 5 specific countries (U.S, China, India, Germany, and South Africa) from the IEA and collected data for each year and the share of modern renewables in final energy consumption from the same source.

Describing Variables:

In our study, we have examined the correlation between an X (independent) and a Y (dependent) variable. Our X variable represents the development status of the country, taking into account the indicators used to denote the development status: HDI (Human Development Index) and the GDP (Gross national Product). The Y variable is the outcome variable, or also the green energy output, which uses the percentage share of energy that is modern renewable (does not include biomass) in the country.

Data Architecture:

Both data sets were merged in R statistical software. For the cross-sectional analysis (year 2022), the original HDI data set contained 193 observations (i.e., countries), whereas the original Renewable data set contained 93 observations. When merged, both HDI and Renew values were present in 63 countries, leaving missing values for 132 countries. Observations with missing values were excluded from the final data set.

For the longitudinal analysis, we created a spreadsheet that included 111 observations from 5 countries: the U.S., China, India, South Africa, and Germany. We collected 20 years of data from these countries, including HDI values and the share of modern renewable energy consumption. These values were then imported into R statistical software for graphical visualization and statistical analysis.

Data Analysis:

We ran correlation and regression analyses to quantify the relationship between HDI and renewable energy consumption as a percentage of total energy consumption within and between countries. Correlation examines the magnitude of the relationship and direction (i.e., positive or negative) but does not tell us about the causality. That is, which variables are the exposure and response. This is easier to implement and is used for exploring the data, which was used on the cross-sectional data. Then, we conducted regression analyses on the longitudinal data to quantify the causal average effect of HDI on total energy consumption within countries. The within-country analysis is useful because it controls for time-invariant country-specific factors that might bias the relationship (like geography, cultural factors, or historical energy infrastructure).

Results:

The figures used 21 years (2000-2021) of data on HDI (Human Development Index) and share of modern renewable energy of 5 countries – China, Germany, India, South Africa, and the United States – to graph the relationships between different values such as the time, HDI, and share of modern renewable energy.

Our analysis reveals important trends in human development and renewable energy adoption across key nations. Figure 1 illustrates the positive correlation between the Human Development Index (HDI) and modern renewable energy usage across the entire dataset, suggesting that more developed nations tend to adopt renewable energy at higher rates.

Looking at development trajectories over time, Figure 2 shows that while Germany and the US have maintained consistently high HDI levels throughout the study period, China, India, and South Africa have made the most substantial developmental gains over these 21 years. This highlights significant progress in emerging economies despite their different starting points.

This development pattern is complemented by the renewable energy trends shown in Figure 3. All five countries increased their modern renewable energy consumption during this period, though at varying rates. Germany stands out with remarkable growth in renewable adoption, while South Africa's progress has been more modest.

When examining the relationship between these two key variables in Figure 4, clear patterns emerge. Germany and the US demonstrate leadership in both metrics, combining high human development with strong renewable energy adoption. China and South Africa occupy the middle ground in both categories, showing balanced but moderate progress. India presents an interesting case, achieving higher renewable energy adoption despite lower HDI scores, suggesting targeted investment in clean energy even during earlier development stages.

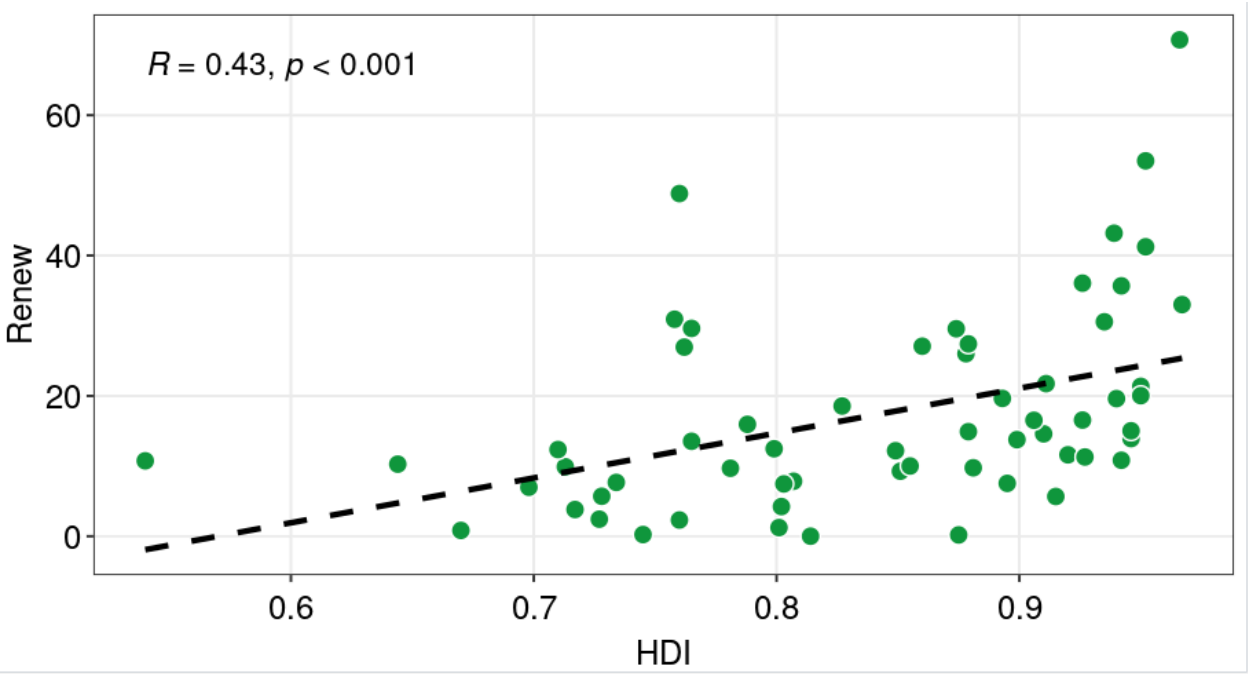

Figure 1. Suggests that there is a positive correlation between a country's HDI (Human Development Index) and its adoption of renewable energy sources. However, in this graph, there are outliers suggesting this is not a perfect representation, and there are other factors that can impact a country's renewable energy output.

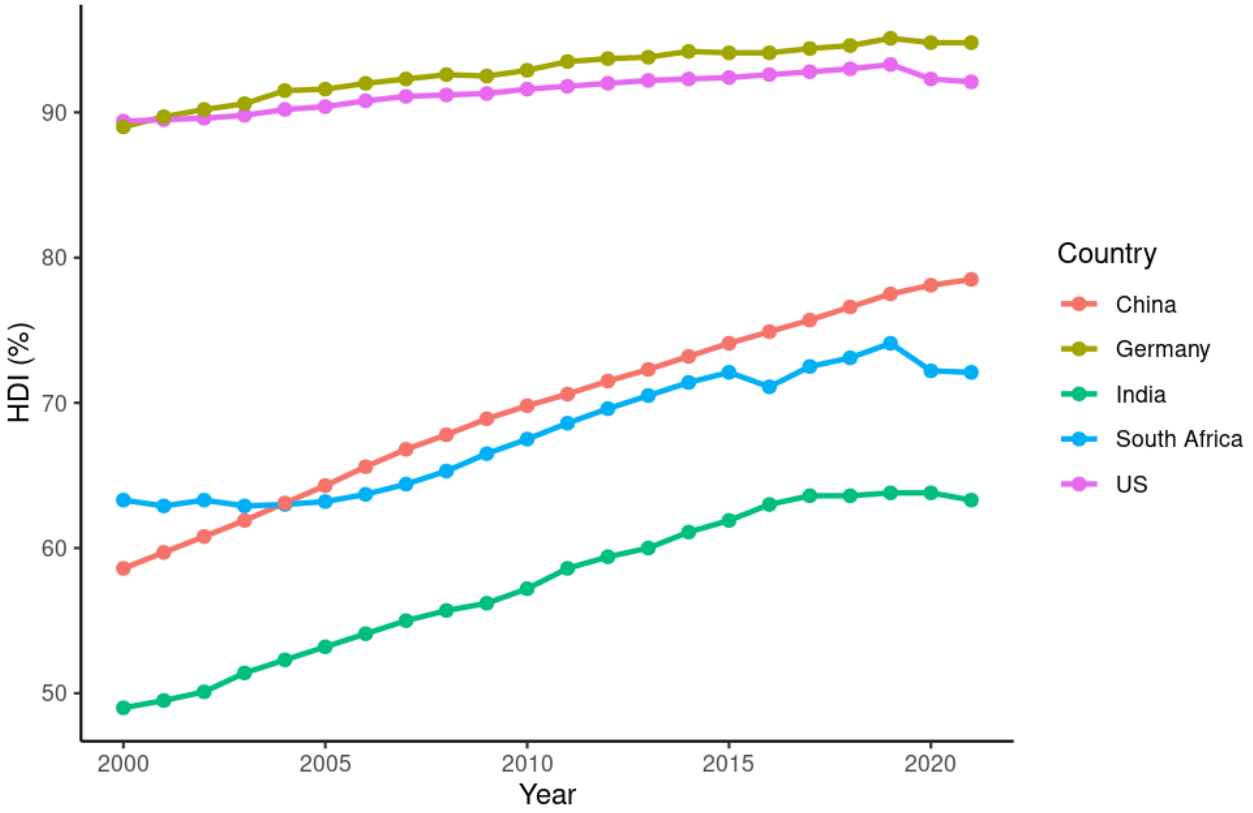

Figure 2. Shows the relationship between years and the Human Development Index (HDI%). HDI is a statistical tool that uses key indicators to measure a country's social and economic well-being. This graph also seems to have a positive correlation as the number of years increases. Specifically, Germany and the United States began with a high HDI percentage of around 90% in 2000, while India, Germany, and South Africa started at a much lower HDI level being below 70%. However, this graph displays that the two countries that happen to have the most growth in their HDI percentage over the years are China, India, and South Africa, while the U.S and Germany maintained relatively the same amount.

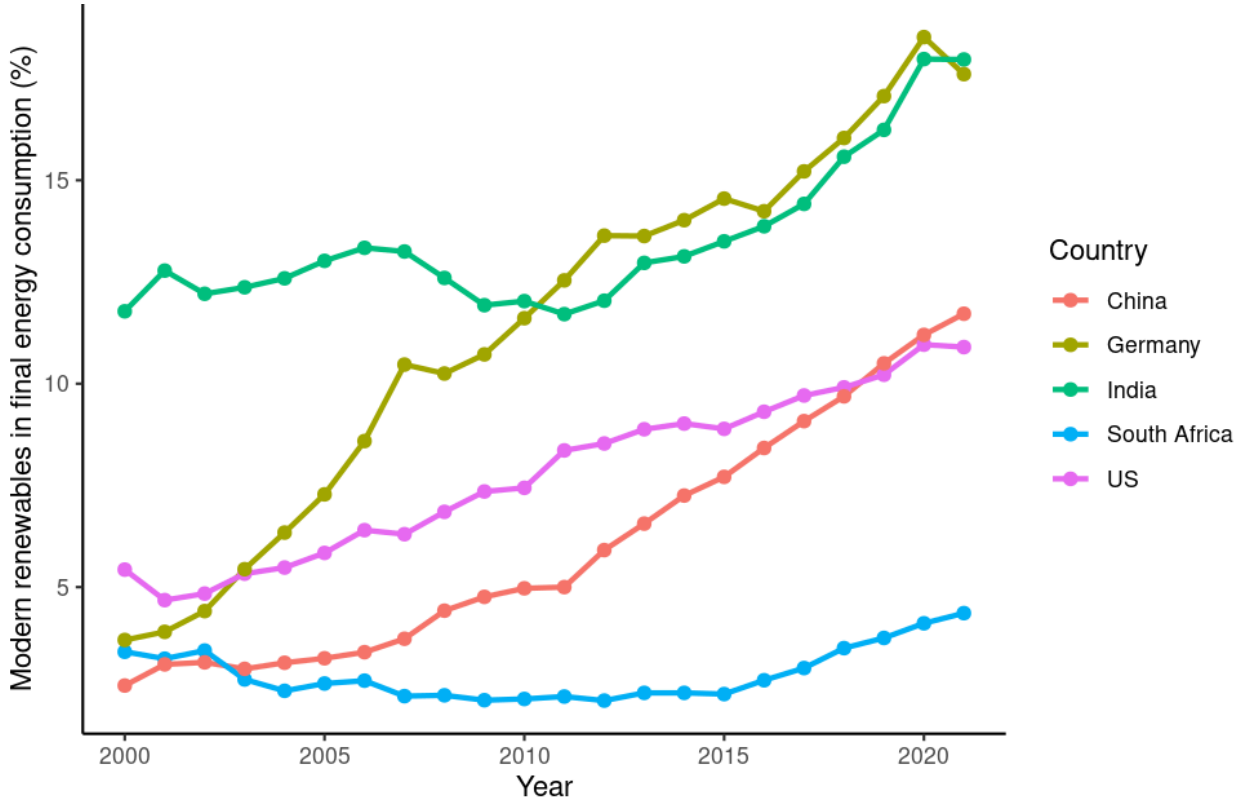

Figure 3. Illustrates the relationship between the consumption of modern renewable energy in the country and the years. Modern renewable energy sources are sources that use the latest technologies to harness power; one example that would not fit these criteria would be biomass. All five countries show an upward trend. Germany has had the greatest increase in the consumption of modern renewable energy over the years compared to other countries. Along with China, India, and the U.S all having a notable increase in the share of modern renewable energy sources. While South Africa has not seen much of this growth maintains its share of modern renewable energy consumption to still be around 5%.

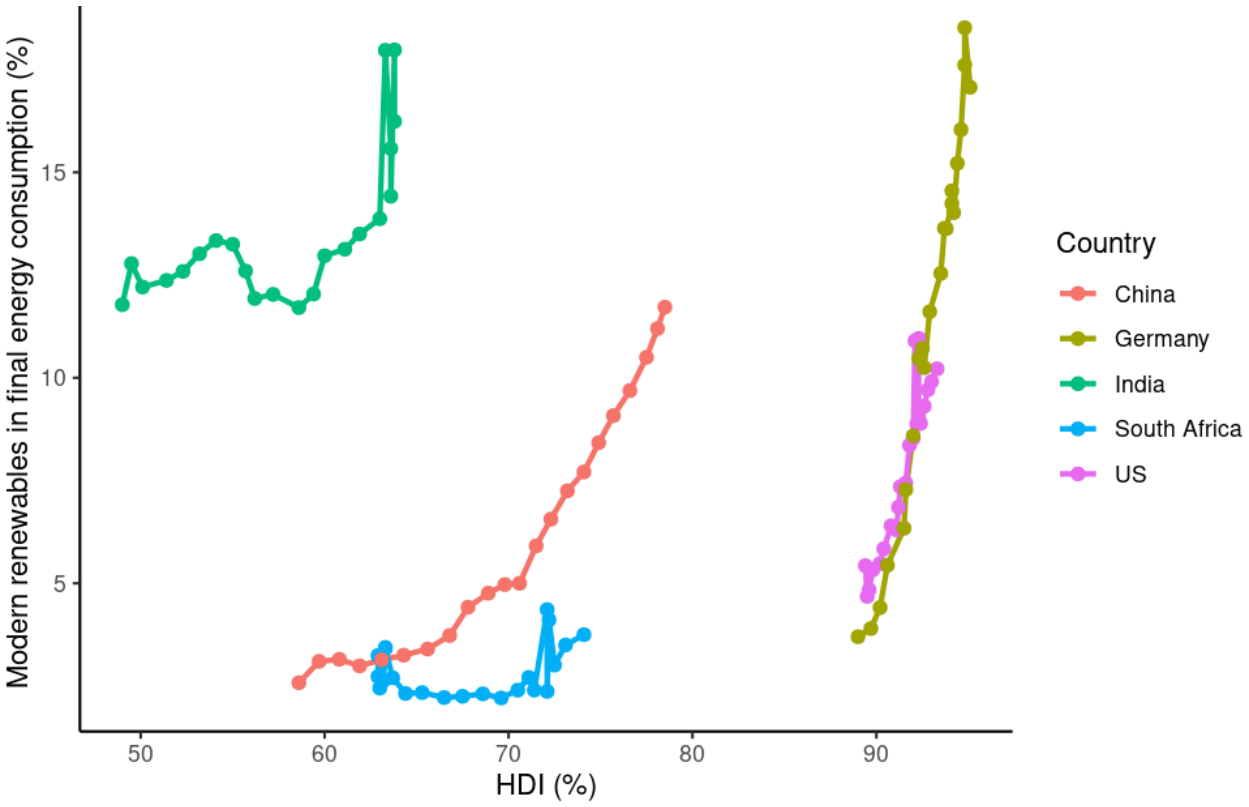

Figure 4: Shows the relationship between the share of modern renewable energy consumption and the Human Development Index (HDI) percentage of 5 countries. HDI is a statistical tool that uses key indicators to measure a country's social and economic well-being. Modern renewable energy sources are sources that use the latest technologies to harness power; one example that would not fit these criteria would be biomass. This graph shows that most countries have a positive correlation between these two variables. Germany and the U.S have a high share of renewable energy as they also have a high HDI percentage. However, India has a much lower HDI percentage while still exhibiting a high share of modern renewable energy. China and South Africa are in the middle, having an equal balance between both.

Table 1 presents our regression analysis examining the relationship between development status and renewable energy adoption across China, India, the U.S., Germany, and South Africa from 2000 to 2020. We measured development status using the Development Index (HDI) while our outcome variable (Y) tracked green energy output through the percentage share of modern renewable energy (excluding biomass) in each country.

Our cross-sectional analysis revealed a modest relationship: a 10 percentage point increase in HDI corresponded with just a 0.4 percentage point increase in modern renewable energy production. This finding was statistically non-significant ($p \approx 0.23$), offering minimal evidence for this relationship.

However, our panel data analysis yielded different results. When examining changes within countries over time, we found that a 10 percentage point HDI increase within a country corresponded with a 4 percentage point increase in renewable energy production. This relationship was highly statistically significant ($p < 0.001$), providing strong evidence that as countries develop over time, they substantially increase their renewable energy adoption.

Table 1: Regression Models Illustrating the Relationship between Human Development Index and Modern Renewable Energy Production

Model	Coefficient	SE	Pvalue
OLS	0.04	0.03	0.23
OLS + Entity FE	0.40	0.05	4.871e-12

Notes: Regression table demonstrating the relationship between HDI and Modern Renewable Energy Production within 5 countries spanning 20 years (2000-2020).

Discussion:

In this section, we are going to discuss some questions that might arise from the figures/graphs. Examining Figure 2. South Africa was decreasing at the start because in the early 2000s, South Africa was experiencing the HIV/AIDS epidemic, leading to a devastating impact on the population's life expectancy. Germany and the US start at an HDI percentage due to their already well-established infrastructure and their high GDP.

Second, in Figure 3, South Africa flat until 2015, then it starts to increase, because the Renewable Energy Independent Power Producer Procurement Programme, an initiative by the South African government, started to yield good results around 2015, leading to the increase. Next, looking at China's graph, China made a big jump in 2011 because of the efforts of China's 12th renewable energy 5-year plan (2011-2015) focused on renewable energy development, boosting modern renewable energy capacity. Germany jumped in 2002-2003 since the EEG (Renewable Energy Act) policy was established and other feed-in tariffs took effect during that time. India starts at a higher modern renewable energy percentage due to India's history of focusing on using biomass as a main energy source, but the graph being flat till 2011 could be the result of the slow implementation of renewable energy policies. Germany's Energiewende program, which promotes modern renewable energy, was very strong and prevalent throughout this time and has helped fuel their growth.

Figure 4 further explores the relationship between HDI and modern renewable energy consumption. China, Germany, and the US's graphs increase rapidly, this may be due to having established policies that boost their modern renewable energy and HDI percentage. Along with this, they are developing countries with political power and money to invest in renewable energy infrastructure. India and South Africa's graphs show a flat trend until high HDI percentages, then there is a spike up and a spike down, which could be on account of new policies being established, and the period of no growth could be a result of slow adoption of new policies.

The regression output provides context for these visual trends. The findings emphasize how countries need to also prioritize both developing HDI and integrating sustainable practices. As one policy won't work for every country, and they need to tailor their policies for the needs of their nation, such as if the country is located in a place where it receives a lot of sunlight, they should be prioritizing the expansion of their solar resources. The models also represent how simply increasing a country's HDI wouldn't lead to an increase in the country's modern renewables, highlighting how countries need to invest in these fields. The contextual significance of this is that a 4 percentage point increase in renewable energy when a country's HDI increases by 10 percentage points represents a meaningful shift in energy infrastructure. For countries with very low renewable penetration, this could more than double their renewable capacity (think China and South Africa). For countries already transitioning (e.g., at 15-20%

renewables), a 4 percentage point increase represents a decent expansion but less than what it would be for small modern renewables.

When countries become more modern (an increase in HDI), they also have better technology, so this could be related to more modern renewables. It is not just an energy transformation but a technological transformation. As countries develop (higher HDI), they gain better technological capabilities. These technological improvements enable more efficient implementation of renewable energy systems (HDI -> Technology -> Renewable). Higher HDI means more educated workforces, better research institutions, and improved governance structures (i.e., less corruption). All of these lead to more innovative energy solutions, where the educated workforce can design, install, and maintain advanced energy systems. Also, research institutions develop and adapt technologies to local conditions, allowing for effective governance to enable supportive policy frameworks.

The regression model assumes that a 10 percentage point HDI increase has the same effect (4 percentage point increase in renewables) regardless of whether a country is moving from HDI 0.3 -> 0.4 or 0.7 -> 0.8. However, in reality, the relationship may be different in these HDI buckets: Low HDI (0.3->0.4): The 4 percentage point increase might primarily come from basic renewable technologies like solar home systems, micro-hydro, or biomass. These countries might be leapfrogging antiquated fossil fuel models (e.g., coal) to decentralized renewables. Middle HDI (0.5 -> 0.6): The 4 percentage point increase might reflect grid-connected renewables (different from solar panels on roofs) starting to replace fossil fuels in the existing energy mix. These countries are building on established infrastructure. High HDI (0.7-> 0.8): The 4 percentage point increase might involve more advanced integration of renewables with sophisticated grid management, storage systems, and smart technology.

Conclusion and Future Direction:

In essence, this study explores the relationship between economic development in countries measured by the HDI value with the percentage of modern renewable energy, hypothesizing that more developed countries would exhibit greater green energy expansion. Compared to the cross-sectional analysis, the longitudinal analysis revealed a stronger link between HDI growth and increased renewable energy consumption within individual countries over time. Confirming our hypothesis that over time, increases in a country's human development result in greater consumption of renewable energy. This finding indicates that human development and rights-focused policies may have indirect but substantial effects on energy composition without explicitly targeting energy sectors**.** For example, a human development policy that invests in technical education for workers, their labor force will be more skilled in the technology industry, and these workers can help build more sophisticated energy systems, leading to more green energy expansion.

Although we are confident in the results of our longitudinal analysis, there are limitations to the analysis. First, we only examined 5 countries over time. We believe our selection of countries represents different growth profiles, but having more countries would increase the reliability of our conclusions, possibly affecting the magnitude of our main result. For example, countries that have heavily invested in fossil fuels like petroleum (e.g., Saudi Arabia) might show a different relationship between HDI and renewable energy consumption. Over time, there might be a sudden change from their main energy source of fossil fuels to modern renewable energy sources due to geopolitical issues or even to reduce their dependence on fossil fuels, such as the UAE. In 2013-2030, the UAE began to invest heavily in solar infrastructure (e.g., Mohammed bin Rashid Al Maktoum Solar Park). Due to the lack of natural resources on an island such as Fiji, they have to import their fossil fuels, which carries high costs. To combat this, Fiji has been investing heavily in renewable energy resources, particularly solar, wind, and hydropower, since these power sources are much more readily available and cost-effective compared to importing their fossil fuels (Keely, 2017). In exchange, this can lead to more of their budget and policies targeting green energy expansion instead of human development and rights-focused policies that would help improve the HDI values of their country.

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