The Effect of GDP per capita on Renewable Energy Production in China

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Abstract

Renewable energy is an important topic in China as the country experiences increased wealth and energy demand. Historically, hydropower has been a valuable source of renewable energy production in China, and will continue to be as the Chinese increase hydroelectric facilities by 2020. Using provincial level data from 1980-2010, this paper estimates the relationship between the percentage of hydropower production and GDP per capita. A linear-log fixed effects model shows that on average, a 10% increase in GDP per capita is associated with a .875 percentage point increase in hydropower production. This translates to a 4.99% increase in hydropower production relative to the sample mean. Increasing hydropower production as a percentage of overall energy production shows that hydropower is growing faster than other sources of energy as GDP per capita grows. This means that hydropower could contribute to mitigating pollution and energy security issues in China.

Introduction

Over the past 30 years, China has experienced rapid industrial development, averaging an economic growth rate of approximately 10% since 1980 ("China Overview" 2014). This trend can be seen in Figure 1 below. With increasing wealth, there has been increasing pollution and energy demand, but these issues can be mitigated with renewable energy. Therefore, this paper investigates the effect of economic growth on the percentage of renewable energy generated using provincial-level data from China for years 1980-2010. It is hypothesized that as provinces become wealthier, they care more about the environment and securing reliable energy sources, leading to increased renewable energy production.

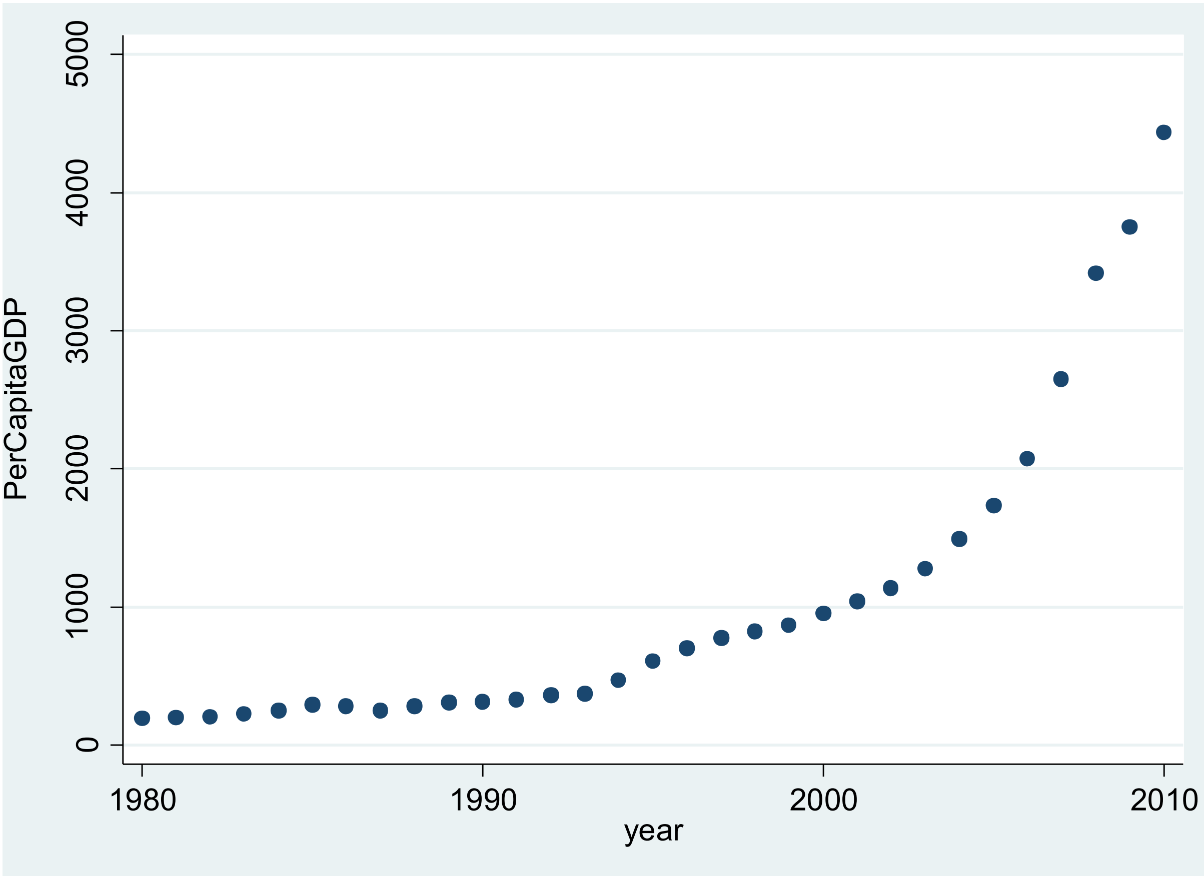

Figure 1 shows the trend of increasing GDP per capita measured as current U.S. Dollars in China from 1980-2010 (The World Bank 2014).

Renewable energy has an average annual growth rate of 6.7% globally, and is expected to be the fastest growing sector of the energy industry from 2005–2030 ("World Energy Outlook" 2007). Recently, it has become a more prevalent source of energy production in countries with both high and low levels of wealth. In the highly developed G-7 countries, income and carbon dioxide emissions have a significant effect on driving renewable energy consumption (Sadorsky 2009). In developing countries, increasing economic growth is increasing energy demand. People of developing nations are becoming richer and improving their living standards, requiring more energy to fulfill their needs. China and India are expected to account for 45% of the increase in world energy demand from 2005-2030 (“World Energy Outlook” 2007). This creates a massive opportunity for renewable energy to become more prevalent in China’s overall energy production and consumption. The increasing trend of renewable energy generation in China can be seen in Figure 2 below. Thus, it is useful to estimate the relationship between economic growth and renewable energy production.

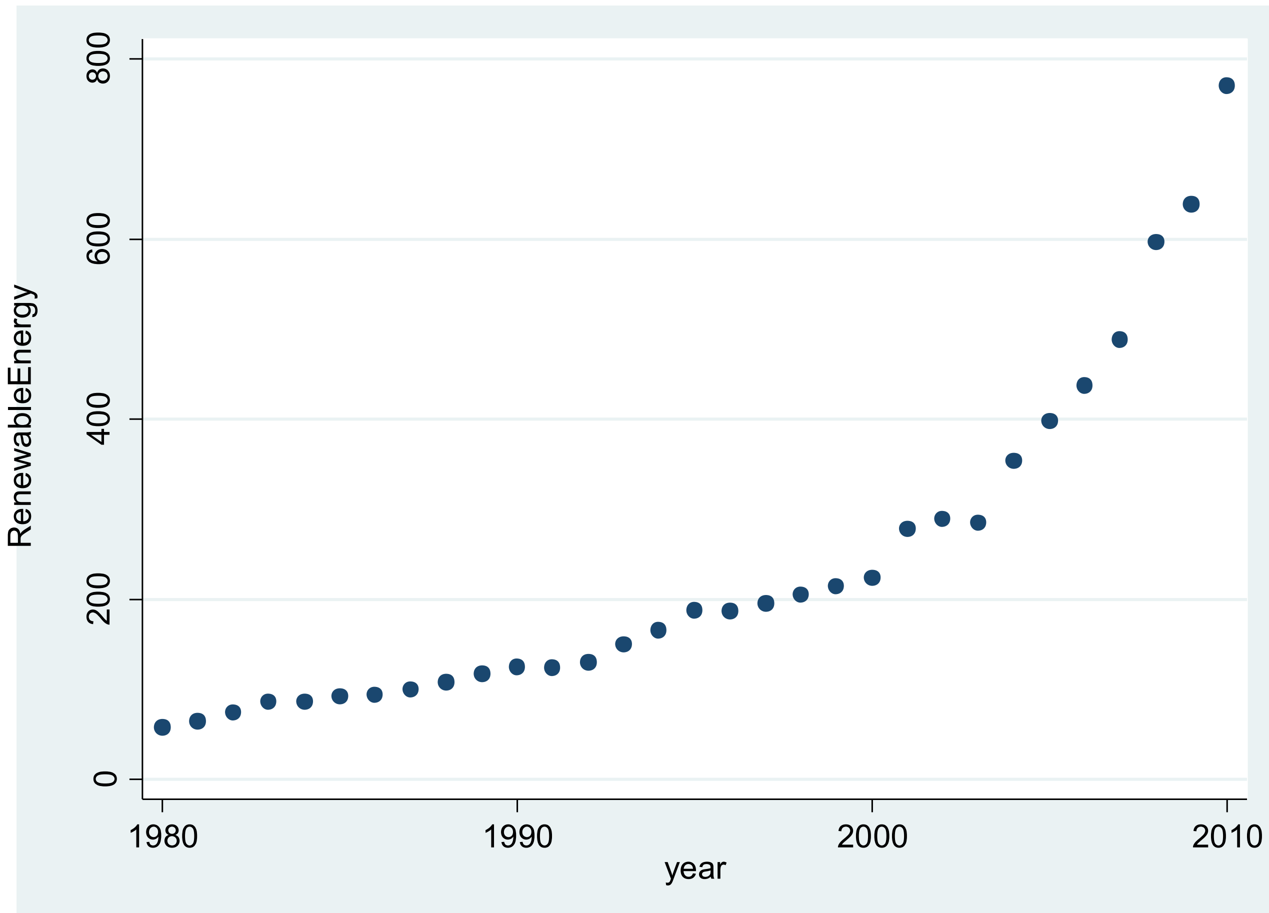

Figure 2 shows the trend of increasing Total Renewable Energy Net Generation (including hydroelectric, geothermal, wind, solar, biomass, and waste generation) measured in Billion kilowatt hours in China from 1980-2010 ("International Energy Statistics" 2014).

Despite the significance of both renewable energy and economic growth in China, there is little existing literature on the relationship between these variables because China's implementation of many alternative energy sources is relatively recent, and data has been limited. Data for this study was accessed from China Data Online, which is affiliated with the University of Michigan. The province-level data reports per capita Gross Domestic Product in Yuan, and renewable energy production, which is measured as the annual percentage of hydropower production out of overall energy production for each province with recorded hydropower data. Hydropower is the predominant source of renewable energy in China, as solar and wind power production are small and more recent. Panel data analysis is conducted using a linear-log fixed effects model that controls for differences in time and province, and province-time trends. Results indicate that on average, a 10% increase in GDP per capita is associated with a .875 percentage point increase, or 4.99% increase, in hydropower production. This indicates that hydropower is growing more quickly than other fuel types in China's energy mix, implying that hydropower has the ability to mitigate pollution and solve energy security issues in the future.

Background

Hydropower, or hydroelectricity, is one type of renewable energy that provides many advantages over other fuel types. It is considered one of the cleanest forms of renewable energy, as it has no direct waste once built and does not contribute further to CO_2 emissions; it is reliable because generation can be easily controlled with dams to meet increases or decreases in demand; it is also flexible because it can implemented on very large scales, very small scales, and nearly anywhere in between. Hydropower has become the most used renewable energy source in the world, and it is especially prevalent in China. They are the largest hydroelectric producer, with the largest hydroelectric facility, in the world ("The Most Widely Used Form of Renewable Energy" 2013).

China provides a unique opportunity to study the relationship between renewable energy production and economic growth. Historically, hydropower has been an important source of renewable energy generation, which has led to adequate record keeping of hydropower production by many provinces. At the same time, China has experienced immense increases in wealth since 1979. Emphasis by the central government on increasing economic growth around this time led to good record keeping and historical data of GDP by province. This creates the possibility for estimating the effect of GDP per capita on renewable energy production in a developing country.

Literature Review

The only existing analysis of the relationship between per capita economic development and renewable energy appears in Sadorsky (2009). The author estimates the relationship between real income per capita and renewable energy consumption per capita for 18 emerging economies, including China, from 1994-2003. The results from this study show that in emerging economies, a 1% increase in real GDP per capita increases renewable energy consumption per capita by 3.39% to 3.45%. Sadorsky's results are consistent with the findings in this paper and support the existence of a relationship between hydropower production and economic growth in China.

The Environmental Kuznet's Curve (EKC) is a concept that supports a relationship between renewable energy production and economic growth in China. It predicts a non-linear relationship between economic growth and pollution. Intuition dictates that as people become wealthier, they care more about their environment and will take steps, such as interest in renewable energy, to mitigate environmental impact. When there is economic growth at low levels of development, there are increasing levels of pollution. However, as economic growth increases at higher levels of development, pollution decreases. Jalil et al. (2009) and Song et al. (2008) both perform studies on the existence of the EKC in China. Jalil et al. (2009) uses carbon dioxide emissions as a measurement of pollution and Song et al. (2008) uses a combination of waste gas, waste water, and solid wastes as a representative of pollution. Both find that this non-linear relationship does hold for China over the long run. However, Harbaugh (2002) conducts a global study on the EKC using a panel data set on ambient air pollution in cities worldwide. Results indicate that there is a weak relationship between income and pollution. Despite this debate, the Environmental Kuznet's Curve provides support for the idea that increasing income leads to increasing renewable energy production, which can decrease pollution.

Pollution in China continues to be a major issue for the country, but this does not mean these problems cannot be solved by renewable energy. According to Can Wang (2005), China is improving their energy intensity, or total energy consumption per unit of GDP. Because of this, the author concludes that fuel switching and renewable energy penetration have a positive effect on decreasing $CO2$ emissions. This shows opportunity for renewable energy incorporation into the energy mix for a positive effect on mitigating environmental impact. Ying Fan et al. (2007) contributes to this idea by pointing out that despite immense growth over the past 30 years, China's carbon intensity, meaning the carbon emissions produced per unit of GDP, has been decreasing. The author suggests that to continue the trend of decreasing of carbon intensity, there must be changes in China's energy portfolio, focusing on renewable energy sources. Can Wang et al. (2005) and Ying Fan et al. (2007) show that China is becoming more efficient with energy production, decreasing the carbon emissions that come with supplying energy, and still increasing their GDP due to changes in the energy industry. The changing energy industry provides an opportunity for China to experience an increasing trend of renewable energy production as GDP increases.

Li Zhidong (2003) forecasts China's economy, energy, and environment to 2030, concluding that GDP growth has the potential to continue at 7% annually. The author suggests that this can happen with rapid policy changes, like switching from coal to natural gas and renewable energy sources. However, rapid policy changes could have major implication on economic growth, causing serious concern among government officials and Chinese citizens. Xing-Ping Zhang et al. (2009) ease these worries by estimating empirical models showing Granger causality from GDP to energy consumption, and Granger causality from energy consumption to carbon emissions. Results indicate that energy consumption and carbon emissions do not generate economic growth. This suggests that the Chinese government can make changes in the energy portfolio without impeding economic growth in the long run. This creates an opportunity for increasing renewable energy use because more renewable energy sources can be consumed and produced without slowing economic growth.

Data

In order to estimate the effect of GDP per capita on renewable energy production in China, this study utilizes data from China Data Online, which is affiliated with the University of Michigan. The sample includes 24 provinces for the years 1980-2010. The selected provinces are those with any reported data for hydropower production. Provinces omitted from this study are those with absolutely no recorded hydropower production data. This means the data provided is not perfect and complete, as some provinces do not have consistent data with recordings for every single year. However, this still provides 744 observations, 641 without any missing data, with each observation representing one year in a given province.

The provincial level variables are GDP per capita and renewable energy production. GDP per capita is measured in Yuan for every province from 1980-2010. Renewable energy production is measured as the percentage of hydropower produced out of China's overall energy production for 24 provinces between 1980-2010. China Data Online provided hydropower data that was not recorded in absolute numbers measured as kilowatt hours like other databases. Instead, hydropower was recorded as a percentage of overall energy production. Hydropower as a percent is useful because it shows hydropower production relative to other fuel productions, such as coal, natural gas, and nuclear production. Increases in hydropower mean that hydropower production is increasing faster than other forms of energy, such as fossil fuels. This can be interpreted as renewable energy becoming more important and more prevalent, which can have a positive impact on mitigating pollution.

The table below displays the means and standard deviations for hydropower production and GDP per capita, which gives a basis for understanding the variables.

Variable	Observations	Mean	Std. Dev.
hydro	641	17.518	24.897
GDP	744	6184.48	7485.536

As can be seen above, hydropower production varies dramatically. Throughout 1980-2010, some provinces produced nearly no hydropower, whereas some only generated hydropower. Variation in hydropower can be seen by looking at the average of 17.5 percent, with a 24.89 standard deviation. This means provinces that are one standard deviation away from the mean are producing approximately 42.712 percent hydropower, which is significantly more than 17.5 percent. At the same time, GDP also experiences a lot of variation, as a province that is one standard deviation from the mean more than doubles their wealth. These numbers provide context for interpreting the relationship between GDP per capita and renewable energy production.

Empirical Models

The empirical models used to test the relationship between GDP per capita and renewable energy production are a linear fixed effects model and a linear-log fixed effects model. A fixed effects model is important for this study because it limits the effects of differences in province and time, thus allowing for a more accurate estimation of the relationship between GDP per capita and hydropower production. Additionally, a province-time variable is created to control for the different trends that occur in each province over a linear time trend. A linear model is initially used to see how gains in GDP per capita using absolute amounts of Yuan can change hydropower production. In other words, the linear model is used to see if a linear equation is the best fit for this set of data. The empirical model that represents the relationship between renewable energy production and GDP per capita is

$$\text{Hydro}_{pt} = \beta_1 \text{GDP}_{pt} + \beta_2 \text{FE}_p + \beta_3 \text{FE}_t + \beta_4 (\text{FE}_p * \text{T}) + \varepsilon_{pt}$$

where *p* is a given province in a given year *t,* Hydro_{pt} is renewable energy production measured as the percentage of hydropower produced, GDP_{pt} is the GDP per capita in Yuan by year and province, FE_t is fixed-effects representing changes over time, FE_p is fixed effects representing changes in the province, (FE_p*T) is the province-time variable measuring changing trends in a province over time, and ε_{pt} is the error correction term.

However, when GDP per capita on the x-axis is graphed against the percentage of hydropower production on the y-axis, it becomes apparent that a linear equation may not be the best fit for this set of data. This can be seen in Figure 3 below.

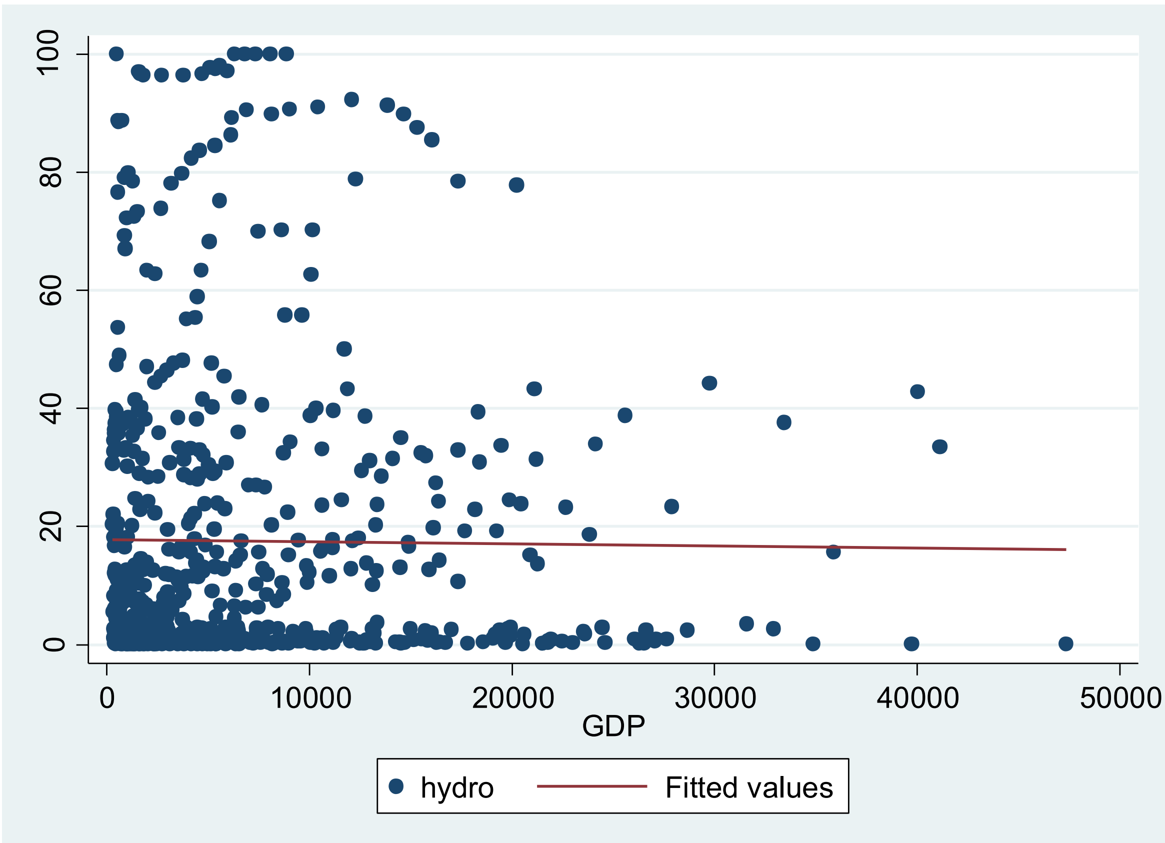

Figure 3 shows GDP per capita graphed against percentage of hydropower production per province in China from 1980-2010. The linear equation does not fit well with the plotted data, and shows a slight decreasing trend.

To further explore this relationship, a linear-log model is used. The linear-log model changes the relationship between the variables to find a better fit for the data by balancing variance. A linear-log model also changes the interpretation of the variables. Instead of comparing Yuan as an absolute number that increases economic growth, GDP per capita is measured as a percent increase, meaning a certain percent increase in GDP per capita has an impact on the percent of hydropower production. This is more meaningful than using 1 Yuan, 10 Yuan, or even 1000 Yuan increments because there is variation in the data that these numbers do not address. A 1% increase in GDP per capita is more relevant because of the large variation in GDP per capita. The equation representing the linear-log relationship between GDP per capita and renewable energy production is

$$\text{Hydro}_{pt} = \beta_1 \ln\text{GDP}_{pt} + \beta_2\text{FE}_p + \beta_3\text{FE}_t + \beta_4(\text{FE}_p * \text{T}) + \varepsilon_{pt}$$

where $\ln\text{GDP}_{pt}$ is the natural log of GDP for a given province at a given time, and all other previously defined variables remain the same. Translating GDP per capita into a log-variable is more suitable for estimating the relationship between GDP per capita and renewable energy production than a linear model.

Results

Results from the linear and linear-log models that estimate the relationship between GDP per capita and the percent of hydropower production out of overall energy production can be seen in Table 2 below.

Findings for the linear fixed effects model indicate that on average, a 1000 Yuan increase in GDP per capita is associated with a .45 percentage point increase in hydropower production in China from 1980-2010. These results are significant at the 5% level. However, the linear relationship does not stabilize the variance in GDP, meaning that a 1000 Yuan increase in GDP per capita can be a large increase for some provinces in China, but a relatively low increase for other provinces in China. Despite this finding, the linear model shows that there is a positive relationship between GDP per capita and renewable energy production in China.

Model	Variable	Coefficient	P-value
FE_Linear	GDP	0.45**	0.022
		(2.30)	
FE_Linear-log	lnGDP	8.7505***	0.008
		(2.65)	
NoFE_Linear	GDP	-0.0356	0.788
		(-0.27)	
NoFE_Linear-log	lnGDP	0.8747	0.269
		(1.11)	

Table 2 shows beta 1 coefficients, t-statistics, and p-values for the linear fixed effects model, the linear-log fixed effects model, and each model without fixed effects.

The linear-log fixed effects model indicates that on average, a 10% increase in GDP per capita is associated with a .875 percentage point increase in hydropower production in China from 1980-2010. This translates to a 4.99% change in hydropower production relative to the sample mean. These results are significant at the 1% level. The magnitude of this relationship is appropriate given that China did actually average a 10% GDP growth rate over the 30 year span this study covers; at the same time, averaging a .875 percentage point increase, or 4.99% change, in hydropower production for every year given the high initial costs, and time to plan and construct facilities, is very reasonable. Therefore, there is a positive and statistically significant relationship between hydropower production and GDP per capita in the linear-log model.

The results for the linear-log and linear models without fixed effects are included in Table 2 above to emphasize the importance of fixed effects in the relationship between GDP per capita and renewable energy production. Without accounting for differences in province and time, and province-time trends, neither the linear or linear-log models produce significant results. There is even a negative relationship between GDP per capita and renewable energy in China using the linear model. The fixed effects model increases the significance of this relationship in both equations and provides much more reasonable beta coefficients.

The positive and statistically significant relationship between GDP per capita and hydropower production has several important implications. An increasing value for hydropower production measured as a percentage of overall energy production for a given province in China shows that hydropower production is increasing relative to other sources of fuel in China's energy mix. In other words, as hydropower production increases, other forms of energy are not growing as quickly, even though they may still exist and remain larger as absolute values. This most likely means that hydropower is increasing faster than different forms of fossil fuels, such as coal, oil, or natural gas (as opposed to other sources of renewable energy, such as solar or wind) due to the time period in which this relationship is estimated. Other sources of renewable energy are recent, thus it would not make sense for hydropower to outpace them from 1980-2010. Instead, hydropower production could be slowly but surely outpacing coal, an abundant but extremely air-polluting fuel in China, or even oil, another environmentally disastrous fuel that has many implications in terms of international relations. This means that China is moving towards renewable energy use relative to fossil fuels, and that hydropower have the potential to mitigate pollution and energy security issues in China.

Conclusion

As China experienced growth for the years 1980-2010, the country also experienced increased energy demand and increased pollution. Renewable energy can play an important role in mitigating these issues. Hydropower is a historically relevant source of renewable energy in China that is connected to increasing economic growth. Both linear and linear-log fixed effects models show that there is a positive and statistically significant relationship between GDP per capita and the percentage of hydropower production. On average, a 10% increase in GDP per capita is associated with a .875 percentage point increase in hydropower production. This means that hydropower production is growing at a faster rate in China than other sources of energy, such as fossil fuels. Therefore, renewable energy production is related to increasing GDP per capita, and can have a positive effect on mitigating pollution and energy security issues.

Further research will be focused on incorporating control variables that have the potential to influence the relationship between GDP per capita and renewable energy production. One variable will be a measurement of capacity, such as average annual rainfall accumulation. and other available fuel sources, such as the amount of fossil fuels a province produces. Rainfall can have an impact on both the independent and dependent variables; it can influence GDP per capita because it can increase the production of other industries, such as agriculture; it can also have an effect on hydropower capacity because more water flow could lead to an increase in a province's capacity to produce hydropower, although China is particularly good at implementing hydropower on large scales and small scales. Another variable will measure the availability of fossil fuels. The availability of fossil fuels can also impact the independent and dependent variables because fossil fuels in a province can impact GDP per capita by decreasing the cost of production for other industries, leading to more economic growth. Fossil fuels can also impact hydropower production because it provides a province with alternative options, which may mean the province does not need to produce hydropower. These variables would both be valuable to control for, and would only further enrich this data set.

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