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A Granger Causality Analysis of China's Energy-Growth Nexus

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Abstract

This paper discusses the subject of economic growth and energy usage, focusing on a singular renewable energy source. The aim is to investigate the causal relationship between hydropower consumption and economic growth in China over the period 1965-2021. To achieve the aim of the study, the Toda-Yamamoto method for the Granger causality test was deployed. The result reports an absence of statistical significance between hydropower consumption and economic growth. The finding implies that no causality is present. Given this finding, it is arguable that hydropower energy consumption cannot be considered as a driving force for enhancing economic growth in China.

Keywords: Hydropower Consumption, Economic Growth, Granger Causality Test

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1. Introduction

In less than half a century, China has emerged from a poor agricultural economy to an industrial powerhouse. The transition was primarily driven by market-oriented economic reforms, successful high-growth strategies, and heavy reliance on energy consumption. In 2009, China surpassed the USA as the world's largest energy consumer and accounted for 24% of total global primary energy consumption in 2021(BP, 2022). The substantial amount of energy consumption usage has confronted China with two notable challenges: energy deficiency and environmental degradation. National energy production companies have experienced increasing difficulty in fulfilling energy demands, especially within the oil sector where shortages became frequently notable in the prior two decades. Such circumstances contributed to the rising energy gap, and thus ensuring energy security has become of high priority (Jiang and Bai, 2017). Temporarily, coal accounts for the largest share of primary energy sources in both production and consumption sectors with 63% and 55% in 2021 (Our World in Data, 2022). The environmental effect of CO_2 emissions is well documented, and it is evident that China´s climate actions are significant for combating global warming. In efforts to mitigate emissions, China pledged to the UN General Assembly to reach peak carbon emissions by 2030 (Min 2021). Consequently, the policies put forth in the 14th Five-Year Plan[1] target to decrease coal dependency and augment non-fossil sources among primary consumption (EIA, 2022).

Since the provision of renewable energy plays a central role in addressing the stated issues, it is necessary to examine the relationship between renewable energy consumption and economic growth. Given that hydropower is currently the largest source of primary consumption among renewable energy, it could provide a solution for sustainable growth and ensure energy security. Therefore, this thesis aims to examine the nexus between hydropower consumption and economic growth. More specifically, it analyses the direction of causality between the variables to determine if growth contributes to increased hydropower consumption, vice versa, simultaneously, or if the linkage is non-existent. Hence this study aims to answer the following research questions:

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[1] The 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Toward 2035 is presented by the Chinese Communist Party

➢ *Is there directional causality between economic growth and hydropower consumption in China?*

There is growing literature on the causal relationship between renewable energy consumption and economic growth across different sets of countries and regions. Many of the studies used causality tests with aggregated energy sources. With the mounting pressure of finding a suitable solution, it is noteworthy to explore the relationship of a singular renewable resource to economic growth, given that empirical results invoke policy implications for policymakers and energy economists (Ummalla, 2018). To explore this relationship, hydropower is deemed as the most suitable renewable source for conducting a set research question. Other renewable energy sources such as solar and wind generate less electricity than hydropower even when combined, given that the development of respective power facilities did not commence before the 2000s (BP, 2022). Attaining national data for energy consumption is an intricate process and is usually reported annually. The lack of data availability among other renewable sources would hamper the result's credibility. Hydropower poses the largest sample size and is thereby the most suitable candidate for conducting the intended statical test.

Yet in the literature, there are few studies inquiring about the nexus of hydroelectricity consumption and economic growth. Ummalla and Samal (2018) examined the nexus between hydropower energy consumption, economic growth, and CO_2 emissions in China. The result found that hydropower energy consumption is a driving force for economic growth. Conversely, Arpegi et al (2016) explored the relationship in the ten largest hydropower energy-consuming countries and found support that economic growth drives hydropower consumption. Ohler and Fetters (2015) found evidence that economic growth and hydropower consumption simultaneously drive each other forward in 20 OECD countries. Ziramba (2015) did not find any direction of causality when investigating the relationship in Egypt. The thesis intends to expand the field of literature regarding the nexus between the variables and hopefully contribute with new insights.

All studies mentioned beforehand use either time series data or panel data and apply similar methods for examining the nexus between the variables to determine the direction of causality i.e., which factor influences the other, if any. Before being able to determine the presence of causality, authors typically conduct variations of cointegration tests to understand long-term relationships between variables. To verify causality an econometrical technique known as the Granger causality test is deployed. Its function is to determine whether one time series can be used to predict another time series. The test hypothesis is that the past value of X contains useful information to forecast Y beyond what is predicted on its past value. (Menegaki and Tungcu, 2016). This paper intends to use a modified version of the Granger Causality test deployed by Toda-Yamamoto (1995) to bypass performing a cointegration test.

The rest of this paper is structured as follows. The first part lays out a theoretical introduction to four different growth hypotheses as well as the Environmental Kuznets Curve. The theories are thereafter linked together with previous research addressing empirical findings relating to the posed research question. The second part of the paper presents the model, discusses empirical strategy, and introduces the Toda-Yamamoto Granger Causality method. The third part provides an overview of the descriptive statistics and analyses the results. The fourth and final part summarizes the paper.

2. Theory and Previous Research

2.1 The Four-Growth Hypothesis

The relationship between energy consumption and economic growth can be classified into four testable hypotheses: The growth hypothesis, the conservative hypothesis, the feedback hypothesis, and the neutrality hypothesis (Arpegis and Payne, 2010). The growth hypothesis implies a unidirectional causal relationship between energy consumption and economic growth. It proposes that an increase in energy consumption leads to economic growth both directly and indirectly as a complement to labor-and-production inputs. The hypothesis also suggests that energy conservation policy may hamper growth. (Apergis and Payne, 2012). The conservation hypothesis asserts a unidirectional relationship running from economic growth to energy consumption which means energy consumption reduction will not impede economic growth, unlike the growth hypothesis. The feedback hypothesis suggests that the relationship between energy consumption and economic growth is interdependent and complementary to each other. Support of this hypothesis requires evidence of a bidirectional causality between the two variables under consideration (Bildirici and Gökmenoğlu, 2017). Finally, the neutrality hypothesis considers energy to have a minor role in the determination of economic growth development. Energy has little to no impact on economic growth. The result required for supporting the neutrality hypothesis is an absence of significance, indicating the presence of no causality between the considered variables. The neutrality hypothesis shares similar traits with the conservation hypothesis by implying that energy conversation policies would not hamper economic growth. (Ummalla, 2018).

2.2 Environmental Kuznets Curve

The environmental Kuznets curve, commonly referred to as the EKC, is an economic hypothesis presented by Simon Kuznet. The hypothesis postulates an inverted-U relationship between various variables of environmental degradation and economic growth. The essence of the theory is that an increased GDP per capita is correlated with an increase in environmental degradation, as increased economic activity implies an increase in the energy usage associated with it. However, as a country reaches a certain stage of development, the use of more efficient and advanced technology will reduce energy consumption. Hence resulting in a U-inverted shape when graphed (Stern, 2018).

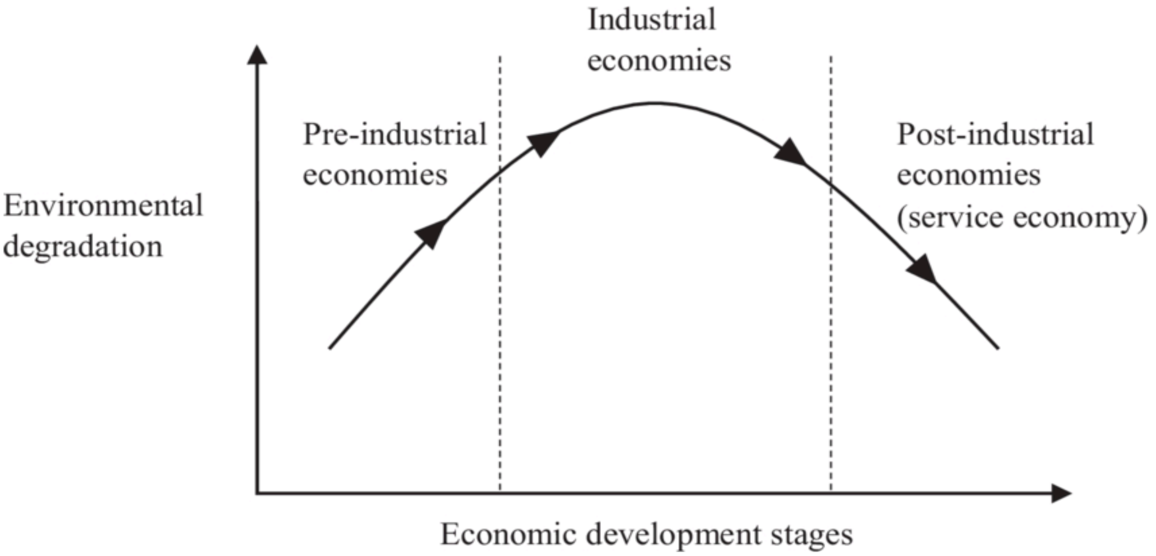

Figure 1: EKC depicting the various stages resulting in an inverted U-shaped relationship (Eren,2022)

The concept of the EKC may provide better insight into understanding hydropower's role in the relationship between energy consumption and economic growth in China. At the initial stage of rapid development, the demand for energy consumption increased and cheap primary energy sources such as coal were combusted to fuel economic activities. As a result, coal dependency increased and homogenized the total energy mix due to its cheapness, efficiency, and abundant natural resources. Extensive coal usage increased CO_2 emissions which led to increasing environmental degradation. To combat the rising emissions rates, hydropower was introduced as an alternative resource to mitigate emissions and the construction of facilities rose the more developed the economy became (Berga, 2016). However, constructing large dams and reservoirs required large quantities of coal-based energy which contributed further to degrading the environment (Berga, 2016). The initial phase of hydropower development suggests that the relationship between economic growth and hydropower consumption might exhibit a positive correlation to environmental degradation. Theoretically, the trajectory of the trend shifts once the threshold is reached. It is characterized by a transition from a positive correlation to a negative correlation i.e., increased economic growth drives hydropower consumption and diminishes environmental degradation. For reaching the turning point, hydropower could be dependent on technological improvement augmenting energy efficiency for contributing to lower energy intensity per unit. Alternatively, environmentally friendly policies are implemented severely enough to create incentives for industries to diminish emission rates and adopt more hydropower.

2.3 Previous research

There are numerous empirical studies dedicated to exploring the nexus between energy and growth. The findings are various and give evidence to support different growth hypotheses. Numerous studies found results to underpin the growth hypothesis. Omri et al (2015) confirmed a one-way causal relationship between renewable energy consumption and economic growth in Sweden, India, Japan, Netherlands, and Hungary. Affirming that renewable energy consumption had a positive impact on economic growth for the specific set of countries for the time frame 1990-2011. Similarly, a study conducted by Brini et al (2017) confirmed the existence of a one-way causality running from renewable energy consumption to economic growth in Tunisia for the period of 1980-20011. Ohler and Fetters (2014) examined the causal relationship between renewable electricity generation and GDP growth for 20 OECD countries between 1990-2008. The result supported the growth hypothesis for hydroelectricity on GDP in the short run. Tiwari's (2011) result pointed towards the causality running from renewable energy consumption to economic growth, thus implying that increasing renewable energy had a positive impact on economic growth in India for the period 1965-2009. Bildirici (2016) examined the relationship between hydropower energy consumption and economic growth in OECD countries with high incomes. The result found evidence to support the growth hypothesis in the short run.

In opposition to the growth hypothesis, other studies found support for the conservation hypothesis. The study of Arpegis et al (2015) analysed the nexus between hydroelectricity and economic growth among the ten largest hydroelectricity consumers between 1965-2012. The result found support for a unidirectional causality running from real GDP per capita to hydroelectricity consumption per capita for the period covering pre-1988. Ocal and Aslan (2013) found a unidirectional causal relationship running from economic growth to renewable energy consumption in Turkey between 1990-2000. Similarly, the study by Dogan (2016) which also covered Turkey, found a unidirectional causal relationship running from economic growth to renewable energy consumption between 1988-2012.

Another set of studies found support for the feedback hypothesis. Sebri and Ben-Salha (2013) investigated the causal relationship in the BRICS over the period 1971-2010. The result indicated a bidirectional relationship between renewable energy consumption and growth, supporting the feedback hypothesis. Arpegis et al (2010) examined the causal relationship between nuclear energy, carbon emission, renewable energy consumption, and economic growth for 19 countries developed and developing between 1984-2007. The result pointed towards a bidirectional relationship. Tugcu, Ozturk, and Aslan (2012) examined the long-run relationship between renewable and non-renewable energy with economic growth for the G7 countries over the period 1980-2009. The result found bidirectional causality for the variables in all countries. Lina and Mubarak (2014) investigated the relationship between renewable energy consumption and economic growth in China over the period 1977-2011. The result showed that a long-run bidirectional relationship was found between the variables.

Some studies did not find any causal relationship between renewable energy and economic growth. For example, Bhattacharya et al (2016) investigated the effect of renewable energy on economic growth in 38 countries between the period 1991 and 2012. The result found no evidence of a causal relationship between the variables. Menegaki (2011) examined the relationship between economic growth and renewable energy for 27 European countries over the period 1997-2007 and the result supported the neutrality hypothesis. Ben et al (2014) found the neutrality hypothesis for 11 African countries between the period of 1980-2008.

As seen from previous studies investigating the energy-growth nexus, authors commonly use aggregate renewable energy as a considerable variable to examine. The following literature review discusses previous studies that incorporated the EKC and used hydropower as a dependent variable. The commonly debated topic when examining the environmental-energy-growth nexus is the legitimacy of the EKC hypothesis and hydropower's impact on the environment. The empirical findings are ambiguous but nevertheless, it is important to analyse the results to gain a better understanding of EKC's relationship to hydropower consumption and growth. Adebayo et al. (2021) examined the hydropower consumption relationship to economic growth, environmental degradation, and urbanization in China from 1965 to 2013. The result confirmed that hydropower consumption improves the quality of the environment in China and validated the presence of the EKC hypothesis for China. Jahanger et al. (2022) investigated the impact of hydropower energy under the EKC hypothesis in Malaysia for the period 1965-2018, The result also found the presence of the EKC and bidirectional causality between CO_2 emissions and hydropower generation. Ummalla and Samal (2018) examined the impact hydropower consumption has on economic growth and CO_2 emission in China for the period 1965-2016. The results failed to prove the support of the EKC but indicated bidirectional causality among economic growth, CO_2 emission, and hydropower energy utilization.

The main takeaway from the empirical findings of the previous research is that the result varies notably depending on which set of regions, observation period, and variables are included. Additionally, the studies preferably use aggregated renewable energy for investigating the nexus between energy and growth.

3. Empirical strategy

To understand this section of the paper, it is essential to restate the research question of the thesis: Is there directional causality between hydropower consumption and economic growth? To answer this question, the relationship between the variables needs to be examined. The previous research found mixed results in the direction of causality by performing causality testing. By doing so, the researcher wanted to confirm if the relationship is unidirectional, bidirectional, or non-directional. Formulated slightly differently the researcher is asking whether an increase in hydropower consumption leads to an increase in economic growth or does an increase in economic growth leads to an increase in hydropower consumption. Maybe the variables are simultaneously affecting each other or perhaps there are no consequences for economic growth if hydropower consumption increases or decreases. The following section starts off by presenting the indented statistical method for conducting the test. It proceeds to showcase the model and finishes off by discussing the sample and data collection.

3.1 The Granger Causality Test

The most practiced method for examining the relationship of time series variables is by using vector autoregression (VAR). It is a statistical modeling technique used to analyse multivariate time series. In such a model, each variable is regressed upon its lagged values and other variables' lagged values. A VAR model handles the variables dynamically and captures all the interactions for accounting endogeneity. Within VAR models, the Granger causality test is commonly deployed for examining a relationship between time series variables. As previously asserted in the paper, the test suggests whether variable X is to Granger cause variable Y if X contains further information for predicting variable Y apart from attained information variable Y gathered from its past value (Menegaki and Tungcu, 2016). The Granger causality test does not implicit the strength of prediction but only affirms the existence of a relationship (Shojaie and Fox, 2021). In the case of two equations with k lags, such as in this thesis, a variable is said to Granger cause another variable if the p-values < given significance level. If statistical significance is observed in both variables, it implies a bidirectional causality. Conversely, if there is evidence of statistical significance being present in only one variable, it implies a unidirectional causality. Following this line of thinking, if the result reveals no sign of statistical significance, it implies that no causality occurs between the variables.

3.2 The Toda-Yamamoto Method

A common problem when utilizing the VAR model is the possibility of a mixed order of integration among the variables. If not dealt with correctly, a mixed order of integration could lead to several issues compromising the reliability and validity of the result. Spurious relationships, misspecification, and incorrect inferences to name a few. To avoid these complications Toda-Yamamoto presented a method for estimating VARs in levels and testing the restriction on coefficients even if the variables are integrated into different orders. This paper applies the proposed method. The first procedure of the Toda-Yamamoto method is to determine the maximal order of integration d_{max}. It is based on the suspected integration that might occur in the process. The next step is to decide the optimal lag length k to estimate an intentionally overfitted causality test so that VAR is $p = k + d_{max}$. This method ensures that the testing focuses on the general restriction, in this case, the Granger causality. This is because the coefficients higher than k are ignored since there regarded as zero due to the overfitting of lags. It allows linear or nonlinear testing on the coefficient to retain standard asymptotic distribution (Toda and Yamamoto, 1995). The model for this thesis is written as follows:

Equation (1)

$$ln\,GDP_t = \alpha_0 + \sum_{j=1}^{k+d\max} \alpha_{1j} \ln GDP_{t-j} + \sum_{j=1}^{k+d\max} \alpha_{2j} \ln HYD_{t-j} + \sum_{j=1}^{k+d\max} \alpha_{3j} \ln URB_{t-j}$$
$$+ \sum_{j=1}^{k+d\max} \alpha_{4,j} \ln IR_{t-j} + \sum_{j=1}^{k+d\max} \alpha_{5,j} \ln OilP_{t-j} + \sum_{j=1}^{k+d\max} \alpha_{6j} \ln CoaP_{t-j} + \varepsilon_{1t}$$

Equation (2)

$$ln\,HYD_t = \beta_0 + \sum_{j=1}^{k+d\max} \beta_{1j} \ln HYD_{t-j} + \sum_{j=1}^{k+d\max} \beta_{2j} \ln GDP_{t-j} + \sum_{j=1}^{k+d\max} \beta_{3j} \ln URB_{t-j}$$
$$+ \sum_{j=1}^{k+d\max} \beta_{4,j} \ln IR_{t-j} + \sum_{j=1}^{k+d\max} \beta_{5j} \ln OilP_{t-j} + \sum_{j=1}^{k+d\max} \beta_{6j} \ln CoaP_{t-j} + \varepsilon_{2t}$$

The *ln,* α *β, t,* and ε represent the natural logarithm, coefficients, time, and error terms which are assumed to be white noise and normally distributed (Ojo, 2014).

Table 1. Variable descriptions and Data Sources.

Variables	Acronyms	Measurement unit	Data sources
GDP per capita	GDP	GDP constant 2015 price level	WDI (2023)
Hydropower consumption per capita	HYD	kWh	B.P (2022)
Urbanization	URB	Urban population as % of the total population	WDI (2022)
Lending interest rate	IR	%	WDI (2023)
Oil price	OilP	Per barrel to 2015 price level	FRED (2022)
Coal price	CoalP	Per tonne to 2015 price level	B.P (2022)

Note. WDI =World Bank Indicator

3.3 Sample and Data

3.3.1 Sample

The data sample in this study consists of annual data from mainland China for the period 1965-2021. The observation period was chosen to collect the largest sample size possible for the dependent variables GDP per capita and hydropower consumption per capita. At the beginning of writing the thesis, the latest data availability was 2021.

3.3.2 Data Collection

The first dependent variable per capita GDP data is collected from the World Development Indicators database and is measured in constant 2015 price level (WDI, 2023). The second dependent variable, hydropower consumption per capita is computed by collecting data from B.P. Statistical Review of World Energy´s 71st edition, converting EJ to kWh, and dividing it by its yearly population using data from the World Bank (B.P 2022; WDI, 2023) The remaining control variables include urbanization rate, oil price, coal price, and lending interest rate and the data sources are found in *Table 1.*

3.2.3 Data limitation

The central limitation of the collected data sample is the irregular extension of historical data. The control variables OilP, CoalP, and IR all respectively date back to 1993,2000 and 1980. The most plausible explanation for the lack of data on natural resources is that the economy did not experience larger-scale effects before the 1990s. As a result, the recording of prices prior was not recorded.

4. Empirical Results

To estimate the direction of causality between hydropower consumption and economic growth the Toda-Yamamoto method for the Granger causality test is deployed. The descriptive data of GDP per capita and hydropower consumption per capita are first presented. It is followed by the result of the main regressions for **Equations (1)** and **Equation (2)**. Finally, three robustness tests are performed to assert the validity and stability of the result.

4.1 Descriptive Statistics

Both GDP per capita and hydropower consumption increased exponentially with time. Notably, both *Figure 2* and *Figure 3* started excelling in growth by the early 2000s relative to the other decades. *Table (1)* showcases the average annual growth per decade[2] and total average growth between 1966 and 2021. The values displayed confirm the visual remarks of *Figure 1* and *Figure 2*. GDP per capita averaged approximately 9% during the 1990s and the 2000s, evading major financial setbacks from the Asian crisis in 1997 and the financial crisis in 2008. Hydropower consumption's maximal annual average growth was 11.5% between 2001 and 2010 and was likely caused by the completion of the Three Gorges Dam (Liu, 2018).

Table 2: Average annual growth rate for dependent variables (WDI 2023; B.P 2022)

Ave rage annual growth rate	GDP%	HYD%
1966-1970	4.54	-0.52
1971-1980	4.33	7.56
1981-1990	7.77	6.62
1991-2000	9.28	4.86
2001-2010	9.93	11.50
2010-2021	6.21	4.81
1966-2021	7.26	6.35

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[2] Except for the 1960´s which is only covers 1966-1970

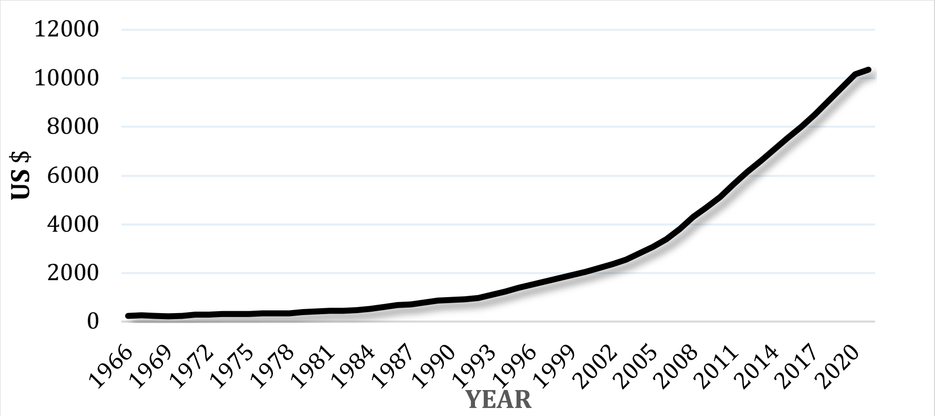

Figure 2. Development of GDP per capita in constant 2015 US $ between 1965 -2021 (WDI, 2023)

The major difference noticed when comparing respectable variables' growth patterns is the variation of average annual growth. GDP per capita indicates more consistent annual growth with a maximum deviation of 5.6% in contrast to hydropower consumption which has a maximal deviation of 12% within the observed period. Indicating that hydropower consumption annual average growth is more volatile.

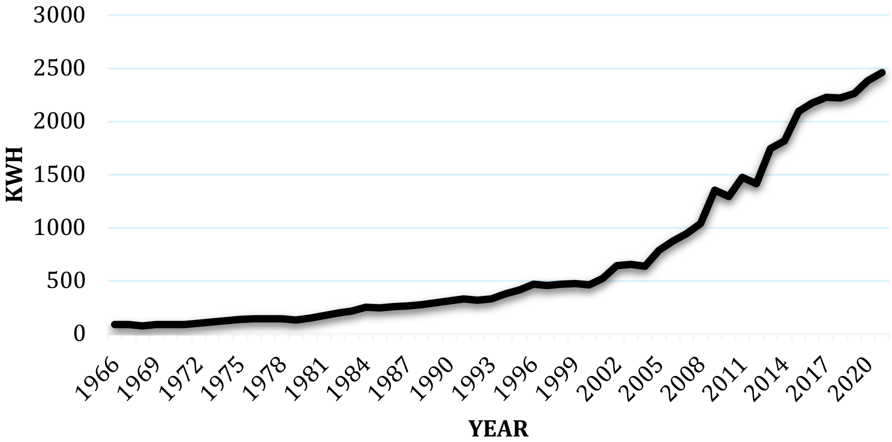

Figure 3. Development of hydropower consumption in kWh per capita (B.P, 2022)

Comparing how much different sources account for in total energy consumption in *Figure 6*, indicates and highlights hydropower's inferiority to fossil fuels, especially coal. The term energy in this context offsets electricity, heating, and transportation, and hydropower is primarily used for electricity production. *Figure 7*, showcases the share of electricity production by source, and notably hydropower accounts for approximately twice the share in comparison to *Figure 6*. The most noticeable trend development however is coal's trajectory which is steadily declining as

China targets to diversify the total energy consumption mix (EIA, 2022) Nevertheless, coal remains a crucial asset to ensure energy security for the years to come (EIA, 2022).

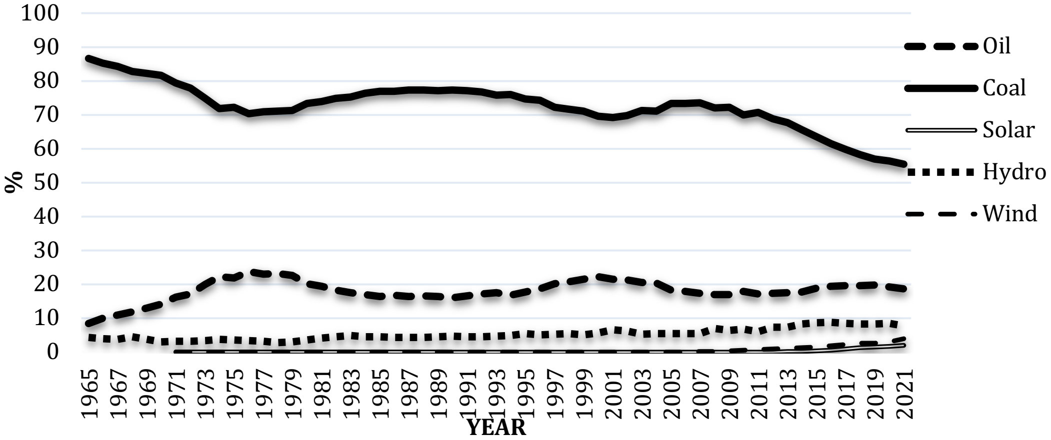

Figure 4. The percentage of energy consumption by source (Our World in Data, 2023)

The development of hydropower has been triumphed by coal in both consumption and production levels, leaving small margins for hydropower to expand properly. The rapid economic development required substantial energy provision for fuelling economic activities and coal provided for a solution. Perhaps the dynamics of the energy mix will alternate in the future but for the time being hydropower is doubtfully large enough as a resource to have impacted economic growth significantly. Therefore, the suspected outcome based on the descriptive statistics is that the result is unlikely to find support for a directional causality when conducting the Toda-Yamamoto method for the Granger causality test.

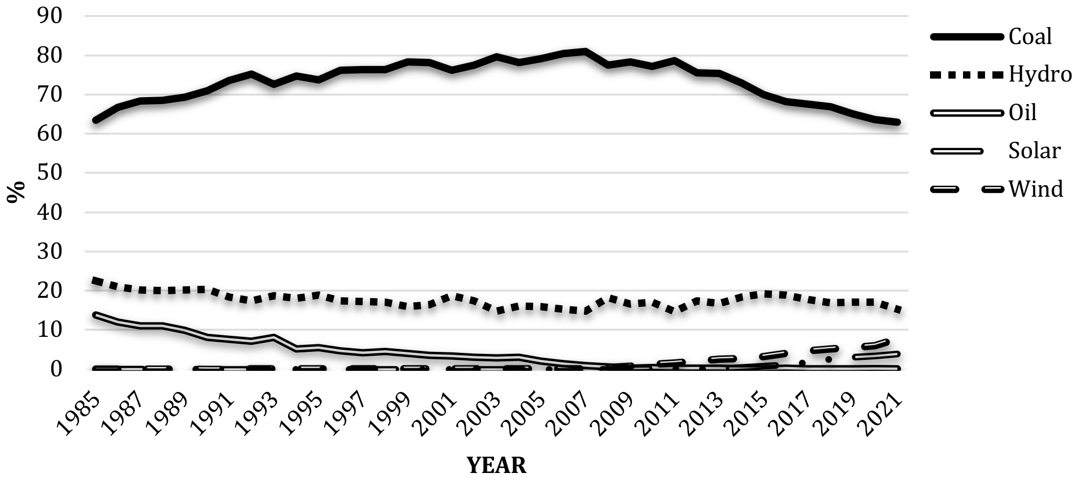

Figure 5. The percentage of electricity production by source (Our World in Data, 2023)

4.2 The Toda-Yamamoto Granger Causality Test Result

Table 2 shows the results from the baseline regression of **Equation (1)** and **Equation (2).** The order of the regressed model follows a left-to-right approach and is indicated by the dependent variable being regressed on all other variables, denoted X. The empirical result indicates no presence of causality between economic growth and hydropower consumption in either direction. The outcome of having no causality gives evidence to support the neutrality hypothesis. The possible factors responsible for having no statistical significance between examined variables could vary. For instance, having a short observation period is not ideal. The baseline regressions included only 19 years due to the shortage of historical data on coal pricing. A small time observation is not favourable but given the weight and importance coal has on the energy sector, the baseline model had to be compromised. Data limitation impedes the credibility of interpreting the *p*-values, hinders trend detections, and is more likely to produce false-positive results (Hacksaw, 2008). In *Table 3* and *Table 5*, there is an argument to be made that the significant *p*-values are a result of the latter statement in the previous sentence.

Table 3. The Toda-Yamamoto Granger-causality test result

	lnGDP → lnX	lnHYD → lnX	Direction of causality
X	*p*-value	*p*-value	
GDP	0.4504	0.2172	~
HYD	0.2172	0.2258	~
URB	0.7689	0.2687	~
IR	0.1627	0.4499	~
OilP	0.0752*	0.1951	lnGDP → lnOilP
CoalP	0.2371	0.1731	~

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

Another plausible explanation for the absence of statistical significance in economic growth and hydropower consumption is due to omitted control variables. Such an omission could consequently cause an underestimation or overestimation of the true size effect, change significance levels, and potentially cause biased estimates (Li, 2021). Perhaps including a non-renewable energy consumption variable would have provided better balance and precision for the model. A third possibility for the absence of statistical significance is that the hydropower sector is simply too small and is therefore not noticed in the aggregated result. Given hydropower's relatively small provision to the overall energy consumption landscape, as seen in *Figure 6*, its influence on economic growth is overshadowed by the coal sector. In summation three plausible explanations might potentially account for the absence of statistical significance between hydropower consumption and economic growth; a short observation period, omitted control variables, and a small hydro sector.

Table 4. Excluding CoalP; Robustness test 1

	lnGDP → lnX	lnHYD → lnX	Direction of causality
X	*p*-value	*p*-value	
GDP	0.1190	0.6349	~
HYD	0.4204	0.2156	~
URB	0.5520	0.1124	~
IR	0.5326	0.4924	~
OilP	0.3381	0.1424	~

** p<0.1, ** p<0.05, *** p<0.01*

There is a scarcity among previous studies whose empirical results concluded no causality between hydropower consumption and economic growth. Ziramba (2013) examined the relationship in Egypt over the period 1980-200 and found support for the neutrality hypothesis. Bildirici (2014) also encountered no causality when investigating the relationship in the United Kingdom between the period 1981-2011. Lau et al (2016) investigated the relationship between hydropower consumption, economic growth, and CO_2 emission in Malaysia for the period 1965-2010. The result found no causality between hydropower consumption and economic growth in the short run. Finally, Zeren and Hizarci (2023) examined the nexus between hydropower energy consumption, foreign direct investment, financial development, and economic growth in newly industrialized countries. The result found there was no causality between hydropower consumption and the three macroeconomic indicators. In comparison to alternative causal relationships, having evidence of no causality is far less observed among the empirical findings.

Table 5. Excluding CoalP and OilP; Robustness test 2

	lnGDP → lnX	lnHYD → lnX	Direction of causality
X	*p*-value	*p*-value	
GDP	0.0000	0.1501	~
HYD	0.3270	0.0002	~
URB	0.4642	0.3805	~
IR	0.2652	0.0178**	lnHYD → lnIR

** p<0.1, ** p<0.05, *** p<0.01*

Table 5. found statistical significance in urbanization, indicating directional causality between economic growth and the urbanization rate for an observation period of 1967-2021. He and Sim (2015) examined and found that economic growth has a statical significance on the urbanization rate.

Table 6. Excluding CoalP, OilP, and IR; Robustness test 3

	lnGDP → lnX	lnHYD → lnX	Direction of causality
X	*p*-value	*p*-value	
GDP	0.0000	0.2263	~
HYD	0.1164	0.0000	~
URB	0.0110**	0.1317	lnGDP → lnURB

** p<0.1, ** p<0.05, *** p<0.01*

In conclusion, there are various factors to consider for the policymaker. The reported result implies that hydropower consumption currently does not provide enough energy support for stimulating growth or the other way around. If the aim is to ensure energy security, decrease coal usage, and sustain economic growth by solely depending on hydropower, policy strategies must be revised. The presented result underpins the necessity for integrating more renewable energy sources to diversify the current energy portfolio and subsidizing R&D to increase energy efficiency. To achieve key targets, policymakers must lobby for greater usage of renewable energy consumption to ensure sustainable growth and energy security.

5. Summary.

The purpose of the thesis has been to analyse the energy-growth nexus between hydropower consumption and economic growth. The hypothesis that directional causality occurs either unidirectional, bidirectional, or non-directional was empirically tested through the Toda-Yamamoto method of the Granger causality test. The result found evidence that a non-directional relationship occurred between hydropower consumption and economic growth, supporting the neutrality hypothesis.

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Appendix

Appendix 1. Granger Causality Tests including all variables

Dependent variable	lnGDP			
Sample Adjusted	2002 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	-1.984736	0.786646	-2.523037	0.0396
lnGDP (-1)	0.256670	0.321125	0.799286	0.4504
lnHYD (-1)	0.128163	0.094523	1.355888	0.2172
lnURB (-1)	-2.055887	6.729370	-0.305505	0.7689
lnIR (-1)	0.070237	0.0045016	1.560271	0.1627
lnCOALP (-1)	0.050006	0.023948	-2.088087	0.0752
lnOILP (-1)	-0.030150	0.023323	-1.292686	0.2371
lnGDP (-2)	-0.430915	0.455864	-0.945271	0.3760
lnHYD (-2)	0.0124204	0.063141	1.967098	0.0899
lnURB (-2)	4.702916	7.357484	0.648009	0.5376
lnIR (-2)	0.052258	0.043459	1.202452	0.2683
lnOILP (-2)	0.008739	0.026516	0.329571	0.7514
lnCOALP (-2)	-0.010304	0.047730	-0.215886	0.8352
R-squared	0.99			
Adjusted R-squared	0.99			

Dependent variable	lnHYD			
Sample Adjusted	2002 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	0.593530	3.899052	0.152224	0.8833
lnHYD (-1)	-0.506117	0.381069	-1.328151	0.2258
lnGDP (-1)	0.761307	0.094523	1.355888	0.2172
lnURB (-1)	38.21848	31.81119	1.201416	0.2687
lnIR (-1)	0.161114	0.201361	0.800124	0.4499
lnCOALP (-1)	-0.156329	0.109130	-1.432508	0.1951
lnOILP (-1)	0.189996	1.25264	1.516765	0.1731
lnHYD (-2)	-0.000599	0.292056	-0.002052	0.9984
lnGDP (-2)	3.315494	2.406371	1.377798	0.2107
lnURB (-2)	-44.74492	34.34767	-1.302706	0.2339
lnIR (-2)	-0.0252652	0.265704	-0.958407	0.3698
lnOILP (-2)	0.291643	0.137753	2.117140	0.0720
lnCOALP (-2)	-0.322679	0.184511	-1.748832	0.1238
R-squared	0.99			
Adjusted R-squared	0.99			

Appendix 2. Granger Causality Tests excluding CoalP

Dependent variable	lnGDP			
Sample Adjusted	1995 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	-1.068325	0.586222	-1.822391	0.0871
lnGDP (-1)	0.513702	0.311852	1.647263	0.1190
lnHYD (-1)	0.037477	0.045298	0.827334	0.4204
lnURB (-1)	-1.586385	2.423095	-0.654693	0.5520
lnIR (-1)	0.018828	0.029517	0.637862	0.5326
lnOILP (-1)	0.013472	0.013642	0.987506	0.3381
lnGDP (-2)	-0.258024	0.273764	-0.9425505	0.3599
lnHYD (-2)	0.087275	0.048563	1.79156	0.0912
lnURB (-2)	3.299984	2.736559	1.205888	0.2454
lnIR (-2)	-0.0252652	0.265704	-0.958407	0.7579
lnOILP (-2)	0.010575	0.013198	0.081274	0.4347
R-squared	0.99			
Adjusted R-squared	0.99			

Dependent variable	lnHYD			
Sample Adjusted	1995 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	1.014156	2.796536	0.362647	0.7216
lnHYD (-1)	0.278588	0.278588	0.216091	0.2156
lnGDP (-1)	0.720172	1.487670	0.484094	0.6349
Ln_URB (-1)	-19.41508	11.55924	-1.679616	0.1124
lnIR (-1)	0.098936	0.140809	0.702631	0.4924
Ln_OILP (-1)	0.100397	0.065079	1.542698	0.1424
lnHYD (-2)	0.270949	0.231667	1.169563	0.2539
lnGDP (-2)	-0.896485	1.305977	-0.686448	0.5023
lnURB (-2)	20.50310	13.05459	1.570566	0.1358
lnIR (-2)	-0.225788	0.162117	-1.392750	0.1827
lnOILP (-2)	0.087996	0.062960	1.397641	0.1813
R-squared	0.99			
Adjusted R-squared	0.99			

Appendix 3. Granger Causality Tests excluding OilP and CoaP

Dependent variable	lnGDP			
Sample Adjusted	1982 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	-0.993100	0.210263	-4.723124	0.0000
lnGDP (-1)	1.098868	0.131394	8.363154	0.0000
lnHYD (-1)	0.036296	0.036442	0.996010	0.3270
lnURB (-1)	0.817520	1.103132	0.741090	0.4642
lnIR (-1)	-0.024482	0.021576	-1.34654	0.2652
lnGDP (-2)	-0.620231	0.112591	-5.508720	0.0000
lnHYD (-2)	-0.051776	0.039283	1.318035	0.1971
lnURB (-2)	0.437979	1.224730	0.357613	0.7231
lnIR (-2)	0.024657	0.019488	1.265269	0.2152
R-squared	0.99			
Adjusted R-squared	0.99			

Dependent variable	lnHYD			
Sample Adjusted	1982 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	0.398958	0.843342	0.0473068	0.6395
lnHYD (-1)	0.612073	0.146164	4.187587	0.0002
lnGDP (-1)	0.777742	0.527006	1.475775	0.1501
lnURB (-1)	3.935964	4.42533	0.889577	0.3805
lnIR (-1)	0.216550	0.086540	2.502317	0.0178
lnHYD (-2)	0.149103	0.157558	0.946334	0.3513
lnGDP (-2)	-0.378183	0.451588	0.837450	0.4087
lnURB (-2)	-4.471824	4.912249	-0.910342	0.3697
lnIR (-2)	-0.270836	0.078163	-3.465004	0.0016
R-squared	0.99			
Adjusted R-squared	0.99			

Appendix 4. Granger Causality Tests excluding OilP, CoaP and IR

Dependent variable	lnGDP			
Sample Adjusted	1967 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	-0.257425	0.149962	-1.716596	0.0925
lnGDP (-1)	1.134208	0.139392	8.136810	0.0000
lnHYD (-1)	0.117984	0.073783	1.599064	0.1164
lnURB (-1)	1.346848	0.509194	2.645058	0.0110
lnGDP (-2)	-0.307237	0.112591	-5.508720	0.0000
lnHYD (-2)	-0.053865	0.070344	-0.765746	0.4476
lnURB (-2)	-1.011498	0.468343	-2.159739	0.0358
R-squared	0.99			
Adjusted R-squared	0.99			

Dependent variable	lnHYD			
Sample Adjusted	1967 to 2021			
Variable	Coefficent	Std. Error	t-Statistics	Prob
C	0.486309	0.289663	1.678878	0.0997
lnHYD (-1)	0.659200	0.124518	4.625527	0.0000
lnGDP (-1)	0.330012	0.269426	1.225689	0.2263
lnURB (-1)	1.508386	0.983545	1.533621	0.1317
lnHYD (-2)	0.000265	0.135874	0.001949	0.9985
lnGDP (-2)	-0.053865	0.070344	-0.765746	0.6165
lnURB (-2)	-2.028065	0.904638	-2.241853	0.0296
R-squared	0.99			
Adjusted R-squared	0.99			