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Impacts of Renewable Energy Transitions on the Economic Growth in Malaysia: A Dynamic ARDL Simulations

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ABSTRACT

This study explores the dynamic relationships between renewable energy transitions and economic growth in Malaysia, with a specific focus on hydroelectric power, using the Dynamic Autoregressive Distributed Lag (D-ARDL) simulations. The research leverages extensive time-series data from 1988 to 2022 to analyze the impacts of hydroelectric and non-renewable energy consumption on the nation's economic trajectory. Our findings indicate a positive long-term relationship between hydroelectric power usage and GDP growth, highlighting renewable energy's pivotal role in sustainable economic development. Additionally, the study examines the short-term adjustments and the effectiveness of hydroelectric power in reducing dependence on non-renewable energy sources, which are crucial for achieving Malaysia's Nationally Determined Contributions (NDC) for 2030. The dynamic ARDL simulations provide nuanced insights into the potential future impacts of increased hydroelectric power usage, underscoring its dual benefits for economic growth and environmental sustainability. This research contributes to the understanding of energy transitions within the context of Malaysia's unique economic and environmental landscape, offering implications for policy and investment in renewable energy infrastructure.

Keywords: Renewable Energy, Hydropower, Economic Growth, Energy Transitions, Dynamic Autoregressive Distributed Lag
JEL Classifications: Q420, Q430

1. INTRODUCTION

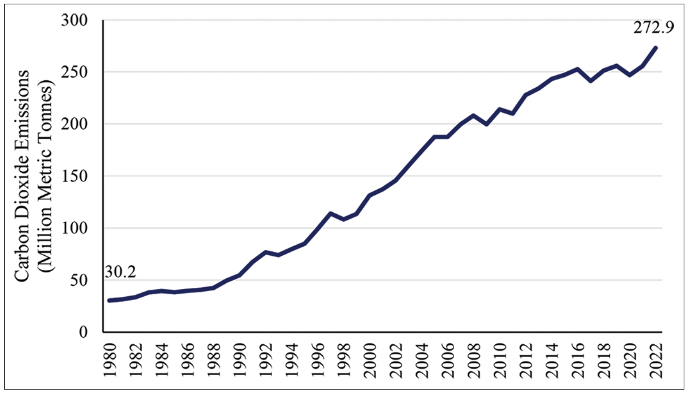
The transition toward renewable energy sources is a critical global endeavor, pivotal for ensuring environmental sustainability and economic resilience. This transition, marked by a shift from conventional non-renewable resources like coal and petroleum to cleaner alternatives such as natural gas, hydrogen, and an array of renewable energies, is essential for sustainable development (Anang et al., 2022). Renewable energies, including solar, nuclear, and wind power, represent a beacon of hope for a sustainable future, aligning with the global movement towards reducing carbon footprints and enhancing energy efficiency (Kabeyi and Olanrewaju, 2022). The Sustainable Development Goals (SDGs) underscore the importance of this transition, particularly through SDG 7, which emphasizes affordable and clean energy, SDG 12, which advocates for responsible consumption and production, and SDG 13, which calls for urgent action to combat climate change. These goals collectively highlight the integral role of energy in shaping a sustainable and equitable global future.

In Malaysia, the significance of renewable energy transcends environmental considerations, touching the very heart of economic growth. Energy is the linchpin of industrial and commercial activities; without it, the production of goods and services grinds to a halt. The transition to renewable energy in Malaysia is not merely an environmental imperative but a strategic economic decision. Renewable sources, particularly hydroelectric power, play a dominant role in the nation's energy landscape, leveraging Malaysia's geographical bounty as a tropical rainforest nation (Ashnani et al., 2014; Bilgili et al., 2021). However, the journey is fraught with challenges. Based on the Energy Institute (2023), the energy generated from petroleum oil, natural gas and coal have an increasing trend throught the years and this led to higher carbon dioxide (CO_2) emission. This can be seen in Figure 1 where there is consistent increasing trend in the CO_2 emissions from the use of fossil fuel energy in Malaysia.

These emissions have far-reaching consequences, exacerbating the greenhouse effect, thinning the ozone layer, and triggering a cascade of climatic alterations (Energy Institute, 2023). The repercussions of these environmental shifts are profound, especially in a country like Malaysia, where the specter of climate change looms large. One of the most palpable impacts is the rise in sea levels, a phenomenon that threatens to reshape coastlines, submerge ecosystems, and disrupt communities. The Intergovernmental Panel for Climate Change (IPCC) Fifth Assessment Report projects a significant increase in sea levels, a change that could have dire consequences for Malaysia's coastal zones, particularly affecting its vital mangrove forests, which are nurseries for marine life and bulwarks against coastal erosion (Asian Development Bank, 2021). These environmental challenges underscore the urgency of Malaysia's energy transition. As the nation pivots towards renewable energy, it navigates a path fraught with complexities yet abundant with opportunities. Renewable energy offers a dual promise: mitigating the adverse effects of climate change while fueling economic growth (Mohamad et al., 2023). This transition is not merely a response to environmental imperatives but a strategic move to harness the economic potential of sustainable energy sources.

In addition, energy transitions play a crucial role in achieving the Nationally Determined Contributions (NDC) 2030, where the Malaysian government has committed to reducing greenhouse gas (GHG) emissions intensity by 45% by 2030 compared to the 2005 levels (Sustainable Energy Development Authority Malaysia, 2023). The latest statistics for 2020 show that Malaysia has achieved a 22% GHG emission intensity, which is still far from the 2030 target of 16% (45% reduction from 2005 levels). However, aside from reaching targets, the way in which transitions in emission intensity affect economic growth remains unclear. While various studies have evaluated the impact of renewable energy consumption on economic growth, there is a lack of

Figure 1: Carbon dioxide (CO_2) emissions from the use of fossil fuel energy in Malaysia



Source: Energy Institute (2023)

research simulating the impacts of renewable energy on economic growth for specific future periods. This is significant because the implications of this transition are profound, affecting various sectors of the Malaysian economy. From industrial production to service provision, the energy sector is the backbone of economic activity. Therefore, understanding the dynamics of this transition, particularly its impact on economic growth, is crucial. This study aims to dissect these dynamics, offering insights into the interplay between renewable energy adoption and economic development in Malaysia.

This article is organized into several key sections to comprehensively address the study objectives. Following the introduction, the Literature Review section explores theoretical frameworks and previous research findings related to the impact of renewable energy on economic growth, with a particular emphasis on hydroelectric power. The Methodology section details the autoregressive distributed lag (ARDL) approach and Dynamic ARDL simulations used to analyze the data, explaining the model specifications and econometric techniques employed. In the Results section, findings from the analyses are presented, highlighting both the long-term and short-term impacts of renewable energy consumption on Malaysia's GDP and compares these findings with existing literature. The Conclusion section that summarizes the key insights, offers policy recommendations, and suggests directions for future research.

2. LITERATURE REVIEW

The Environmental Kuznets Curve (EKC) theory elucidates the dynamic relationship between economic growth and environmental degradation, initially employed to examine income disparities and delineate an inverted U-shaped correlation (Kuznets, 1955 ; Kaika & Zervas, 2013). Grosman and Krueger (1994) expanded this framework to explore the nexus between environmental pollution and income levels, asserting that initial economic growth exacerbates environmental degradation, whereas subsequent development enhances environmental quality through technological advancements and prioritization of sustainability (Kongkuah et al., 2021; Zhou, 2019). The discourse on the interplay between energy and economic production unveils two divergent viewpoints. The neoclassical growth theory posits a negligible correlation between energy consumption and economic output, emphasizing capital and labor as pivotal factors, with technology playing a critical role in enhancing productivity (Hasanov et al., 2017; Camarero et al., 2015). This perspective aligns with the Harrod-Domar and Solow-Swan models, which exclude energy as a direct input in the production function (Lee and Chang, 2008; Camarero et al., 2015). Conversely, an alternative perspective champions the significance of energy in the production process, proposing models like the augmented Cobb-Douglas production function that incorporates energy alongside capital and labor as essential inputs (Barro, 1990; Hamilton, 1983). Rahman and Velayutham (2020) further refined this model by integrating renewable and non-renewable energy sources as distinct production factors.

The pivotal role of renewable energy in fostering economic growth is increasingly recognized (Mbarek et al., 2016; Gyimah et al.

2022; Shahbaz et al., 2020. Kouton (2020) demonstrated that renewable energy consumption has a more pronounced effect on economic growth compared to the reverse relationship. Inglesi-Lotz (2016) corroborated this, highlighting the positive impact of renewable energy utilization on economic expansion. The global shift towards sustainable electricity production is characterized by an increased reliance on renewable sources, such as solar, wind, and nuclear energy, which simultaneously contributes to carbon emission reduction (Kabeyi and Olanrewaju, 2022). Empirical evidence underscores the significance of renewable energy in driving economic prosperity across various regions. For instance, Zrelli (2016) identified renewable energy as a crucial factor in the economic growth of Mediterranean countries between 1980 and 2011. Similarly, Kouton (2020) observed a positive correlation between renewable energy consumption and inclusive growth in 44 African nations over the period 1991-2015. These findings align with studies conducted in diverse geopolitical contexts, including OECD countries (Inglesi-Lotz, 2016), South Asian nations (Rahman and Velayutham, 2020), Sub-Saharan Africa (Vural, 2020), and selected Asian countries (Wang et al., 2022).

Several studies in China found that hydropower can reduce pollution and increase economic growth (Ummalla and Samal, 2018; Li et al., 2021). The BRICS countries also obtained the same result through the use of hydrological energy which has a positive impact on economic growth, both in the long and short term (Ummalla et al., 2019). The study by Zhang et al. (2021) for South Asian Association for Regional Cooperation (SAARC) countries show that all three types of renewable energy, namely hydro, geothermal and wind have a positive impact on economic growth, especially hydro energy sources. Next, Acaroğlu et al. (2023) proved that EKC is valid in Turkey because the use of hydropower reduces greenhouse gas emissions and ensures that economic growth remains sustainable. In the context of Malaysia, the relevance of the EKC theory is evident in studies focusing on renewable energy's role in economic growth. Bello et al. (2018) and Sinaga et al. (2019) validated the EKC hypothesis in Malaysia through the lens of hydropower utilization employing the Auto Regressive Distributed Lag (ARDL) approach. Afroz and Muhibbullah (2022) explored this relationship using the Nonlinear Auto Regressive Distributed Lag (NARDL) model, noting the economic implications of the cost differentials between renewable and non-renewable energy sources.

3. METHODOLOGY

To examine the impact between renewable energy consumption on the economic growth in Malaysia, this study utilize the Autoregressive Distributed Lag (ARDL) method and also the extension of ARDL which is known as Dynamic ARDL. The model used in this study are based on Vural (2020) as follow:

$$GDP_t = c + \beta_0 HYD_t + \beta_1 NRE_t + \beta_2 K_t + \beta_3 L_t + \varepsilon_t \quad (1)$$

Where GDP are Gross Domestic Product, HYD are hydropower energy consumption, NRE are non-renewable energy consumption, L are labor, and K are capital. There are several steps that need to be carried out first before performing the ARDL test, namely by determining the optimal lag to ensure that the max lag that will be used is appropriate through the VAR test. The goodness of fit test used is the Schwarz information criterion (SIC). The model for ARDL is as follow:

$$\begin{aligned}\Delta \ln GDP_t &= \alpha_0 + \sum_{i=1}^{p}\theta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^{q}\theta_2 \Delta \ln HYD_{t-i} \\ &+ \sum_{i=0}^{r}\theta_3 \Delta \ln NRE_{t-i} + \sum_{i=0}^{s}\theta_4 \Delta \ln K_{t-i} + \sum_{i=0}^{t}\theta_5 \Delta \ln L_{t-i} \\ &+ \delta_1 \ln GDP_{t-1} + \delta_2 \ln HYD_{t-1} \\ &+ \delta_3 \ln NRE_{t-1} + \delta_4 \ln K_{t-1} + \delta_5 \ln L_{t-1} + V_t \end{aligned} \quad (2)$$

Based on the ARDL model above, Δ denote differences, p,q,r,s and t denote optimal lag length determined by SIC. The parameter $\theta_1,\theta_2,\theta_3,\theta_4$ and θ_5 are short-run coefficients, while, δ_1, δ_2, δ_3, δ_4, and δ_5 are the long-run coefficients and V_t are the error terms. The ARDL method begin with the testing the cointegration in the model by using F-bound test developed by Pesaran et al. (2001). Cointegration shows the existence of a long-run relationship between variables. Where the null hypothesis states that there is no cointegration, while the alternate hypothesis states that there is cointegration. Meanwhile, the short-term relationship is tested through the error correction model (ECM) to estimate short-term coefficients and adjustment coefficients (Sanusi et al., 2018; Asri et al., 2018; Kanjilal and Ghosh, 2014). The model for ECM is as follow:

$$\begin{aligned}\Delta \ln GDP_t &= \alpha_0 + \sum_{i=1}^{p}\theta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^{q}\theta_2 \Delta \ln HYD_{t-i} \\ &+ \sum_{i=0}^{r}\theta_3 \Delta \ln NRE_{t-i} + \sum_{i=0}^{s}\theta_4 \Delta \ln K_{t-i} + \sum_{i=0}^{t}\theta_5 \Delta \ln L_{t-i} \\ &+ \Psi ECM_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

ECM_{t-1} is:

$$\begin{aligned}ECM_t &= \ln GDP_t - \alpha_1 - \sum_{i=1}^{p}\varnothing_{1i} \ln GDP_{t-1} - \sum_{i=0}^{q}\beta_{1i} \ln HYD_{t-1} \\ &- \sum_{i=0}^{r}\theta_{1i} \ln NRE_{t-1} - \sum_{i=0}^{s}\lambda_{1i} \ln K_{t-1} - \sum_{i=0}^{t}\vartheta_{1i} \ln L_{t-1} \end{aligned} \quad (4)$$

Where, ECM is the lag error correction term and the symbol ψ indicates the adjustment speed. The ECM coefficient serves to measure the adjustment back to the equilibrium level. The advantage of ARDL is not only being able to see long-term and short-term relationships, but also being able to analyze the level of stationarity of the data either stationary at the level I (0) or stationary at the first difference I (1). Furthermore, it can analyze cointegration in studies that have a small number of data (Pesaran et al., 2001).

Next, this study also conduct the dynamic ARDL to study the impact of hydroelectric energy use on economic growth in Malaysia for the future. Dynamic ARDL simulation was developed by Jordan and Philips (2018) who also introduced a dynamic error - correction mechanism. Using this, the results of this study can help the government and investors to further develop the use of hydroelectric energy. Sarkodıe and Owusu (2020) explains how dynamic ARDL is clearly done to see what happens to economic growth when nuclear power in Switzerland is reduced from 2018 to 2038. Therefore, this study is carried out in Malaysia to study the implications of higher reliances of hydro in electricity generation to have a positive or negative impact on the country. The model for dynamic ARDL simulation is:

$$\Delta \ln GDP_t = \delta_0 + \alpha_0 \ln GDP_{t-1} + \vartheta_1 \Delta \ln HYD_t + \alpha_1 \ln HYD_{t-1} + \vartheta_2 \Delta \ln NRE_t + \alpha_2 \ln NRE_{t-1} + \vartheta_3 \Delta \ln K_t + \alpha_3 \ln K_{t-1} + \vartheta_4 \Delta \ln L_t + \alpha_4 \ln L_{t-1} + \varepsilon_t \quad (5)$$

Where, δ_0 is a constant term, α_0 is the coefficient of the error correction term. $\vartheta_1, \vartheta_2, \vartheta_3$ and ϑ_4 is a short-term coefficient. While, $\alpha_1, \alpha_2, \alpha_3$ and α_4 are long-term coefficients and ε_t are error terms. The dynamic ARDL technique has been used in several studies to identify future shocks in socioeconomic and climate indicators. Policies are made based on specific inputs to see potential shocks if hydroelectric power is increasingly accessed. According to BP, the contribution of hydro energy use in 2022 is as much as 19% and the target contribution of hydro to the use of renewable energy in 2035 is as much as 40% (MIDA, 2022). This simulation was done to study the impact of the use of hydroelectric energy on economic growth in a period of 13 years. Shockvar is used in this simulation to study shock potential. Where, shockval is the amount of shock applied to the target variable.

This study expects hydroelectric energy to have a positive impact on the country's economic growth. This is because Malaysia is a country that has a large rainwater catchment area and receives rain throughout the year. Furthermore, hydro energy is a source of energy that will not run out and can be accessed throughout the year as well as reducing environmental pollution. Meanwhile, the use of energy from crude oil, natural gas and coal also has a good impact on economic growth as we can see now. However, the use of non-renewable energy sources has a negative impact on the environment because it releases greenhouse gases. This energy source also cannot be extracted forever from the earth's crust because it is limited and requires a very long period of time to form under high pressure.

In addition, gross fixed capital investment can also increase economic growth. Investment is an injection to national income. Where investment increases, national income will also increase. This is because, investment can open more job opportunities and increase production through the use of advanced technology. Another variable is labor, labor is a very important workforce to develop economic growth. This is because, through labor, goods and services can be produced. The more the use of labor increases, the productivity of a firm will increase indirectly further developing the country's economic growth.

KRLS is used to see the relationship between cause and effect through pointwise derivatives. Based on the target percentage of hydro energy use in 2035 against economic growth, structural changes in economic growth can be seen by using empirical expectations based on pointwise marginal effect. The marginal effect of heterogeneity is evaluated through regression derivatives at the 25th, 50th and 75th percentiles. If the marginal effect of heterogeneity does not occur against the variable sample, this indicates that the pointwise derivatives are robust.

This study also conduct the unit root test to test the stationarity of the dependent variable and the independent variable used in a study. The stationarity of the variables used in the model was tested using Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF). The stationarity of the dependent variable is at I (1) only, while the stationarity of the independent variable is at I (0) or I (1) but cannot exceed I (1). The stationarity of the independent variable cannot exceed I (1) to avoid the occurrence of autocorrelation, structural break, and heteroskedasticity. In addition, several tests are performed to detect autocorrelation, multicollinearity, heteroskedasticity and violation of normality. The tests used are Durbin Watson test for autocorrelation problem, Breusch Pagan Godfrey test for heteroskedasticity, VIF test for multicollinearity and normality test for violation of normality. This diagnostic test is very important to ensure that the research carried out is relevant.

The data used in this study is from 1988 to 2022 which is for 35 years for Malaysia. The data are obtained from various sources, including local sources and international database. Detail informations on each variables used in this study are provided in Table 1.

4. RESULTS

Table 2 shows the mean, median, maximum, minimum, standard deviation, skewness and kurtosis values for GDP, HYD, NRE, GFCF and L. Results shows that the GDP and GFCF variables are skewed to the left, meanwhile HYD, NRE and are skewed to the right. The same can be explained based on the mean and median values.Furthermore,

Table 1: Variable information

Variables	Units	Source
GDP	Constant 2015 USD	World Bank
Electricity generation from hydro (HYD)	Twh	Energy Institute
Electricity generation from nonrenewable energy sources (NRE)	Twh	Energy Institute
Gross fixed capital formation (K)	Constant 2015 USD	World Bank
Labor (L)	Million	DOSM

GDP: Gross domestic product, Twh: Terawatt-hours, DOSM: Department of Statistics Malaysia

Table 2: Descriptive statistics

Statistics	GDP	HYD	NRE	GFCF	L
Mean	5.6955	7.0591	7.4998	6.9137	2.6490
Median	5.8127	5.1780	5.2003	6.2637	2.0694
Maximum	10.0027	68.8889	22.6244	28.0203	9.1586
Minimum	−7.3594	−24.5283	−7.3480	−42.9660	0.5526
SD	3.9963	19.3292	7.1098	13.2706	1.9870
Skewness	−1.6688	1.0424	0.4922	−1.2593	1.9290
Kurtosis	5.95523	4.4172	2.6223	7.0305	6.6012

GDP: Gross domestic product, HYD: hydropower energy, NRE: non-renewable energy, GFCF: gross fixed capital formation, L: labor

HYD and GFCF have high standard deviation, compared to the other variables. Next, this study proceeds with unit root test to indentify the stationarity of each variables. Based on Table 3, both ADF and PP shows that all variables are stationary at level and no variables that are stationary at second difference. Hence, this support the justification in this articles to proceed with ARDL estimation.

Prior to reporting the short-run ARDL results, this study established the long-term relationship between variables using the F-statistic value in the bound test. Results as reported in table below shows that it is significant at 1% indicating existence of long-run relationship between hydroelectric consumption, non-renewable energy, gross fixed capital formation and labor on the economic growth in Malaysia. The short run estimation results are also reported in Table 4 which shows that previous year GDP have positive and significant impact of current year GDP. This is expected from the momentum impact. While GFCF and HYD had mixed short run impact on the GDP. No significants short run impact are found between non-renewable energy and GDP. Table 4 also shows the error correction term (ECT) which is used to estimate the speed of equilibrium adjustment for GDP in Malaysia due to any shock in the explanatory variables the short term. The coefficient value for ECT is negative and significant at 1% indicating that GDP will take an adjustment time of 10 months to return to equilibrium.

Table 3: Unit root results

Variables	PP		ADF	
	Level	First difference	Level	First difference
GDP	−5.2609***	−16.4222***	−4.8140***	−7.5433***
HYD	−9.8393**	−16.0548***	−5.3481***	−6.6659***
NRE	−5.4646***	−21.2943***	−5.4719***	−5.4719***
GFCF	−4.2514***	−15.6077***	−4.3429***	−4.3429***
L	−5.5036***	−11.9970***	−5.5047***	−5.4719***

PP: Phillips-Perron, ADF: Augmented Dickey-Fuller, GDP: Gross domestic product, HYD: hydropower energy, NRE: non-renewable energy, GFCF: gross fixed capital formation, L: labor. *** and ** denote significant level at 1% and 5%, respectively

Table 4: Autoregressive distributed lag estimation results

Variables	Coefficients	SE
Short run		
Δhor_{t-1}	0.3879***	0.0959
$\Delta.095_{t}$	0.2228***	0.0173
$\Delta.017_{t-1}$	−0.0567**	0.0289
$\Delta.028_{t-2}$	0.0352**	0.0179
$\Delta.017_{t-3}$	0.0771***	0.0152
$\Delta.01_{t}$	0.1055***	0.0113
$\Delta.01_{t-1}$	−0.0437***	0.0104
$\Delta._{t}$	0.0814	0.1119
$\Delta._{t-1}$	0.0023	0.1233
$\Delta._{t-2}$	−0.1120	0.1192
$\Delta._{t-3}$	−0.3873***	0.1137
ECT_{t-1}	−1.1892***	0.1038
F-statistics	16.121***	
Long run		
$GFCF_{t-1}$	0.1345***	0.0474
HYD_{t-1}	0.0889***	0.0321
L_{t-1}	−0.1779	0.1966
NRE_{t-1}	0.3193***	0.0650
Constant	2.4497***	0.5833
Diagnostic test		
Breusch-Pagan-Godfrey	1.7765	
Jarque-Bera	0.6869	
Serial correlation LM test	0.2284	
Ramsey's RESET test	11.8707***	
CUSUM	Stable	
CUSUM square	Stable	

SE: Standard error, GDP: Gross domestic product, HYD: hydropower energy, NRE: non-renewable energy, GFCF: gross fixed capital formation, L: labor. *** and ** denote significant level at 1% and 5%, respectively.

Table 4 shows that all variables such as HYD, NRE, and GFCF are significant at the 1% level and show a long-term relationship with the GDP variable. However, L does not have a long-term relationship with GDP. An increase of one unit in HYD electricity generation will increase GDP by 0.09%. Ullah et al. (2024) also proved that hydroelectric power generation has a positive effect on economic growth and financial development as it can reduce energy dependence from other countries. However, Malaysia still heavily depends on fossil fuels compared to renewable energy sources as a 1% increase in NRE electricity generation will increase GDP by 0.32%. The diagnostic test results indicates that there are no problems with heteroscedasticity (Breusch-Pagan-Godfrey), normality (Jarque-Bera), and autocorrelation (Serial Correlation LM test). Meanwhile, Ramsey's RESET Test indicates the presence of model specification issues such as omitted variables, incorrect functional form, and correlation between independent variables and error terms. CUSUM for parameters and CUSUM Square for error term variances are stable.

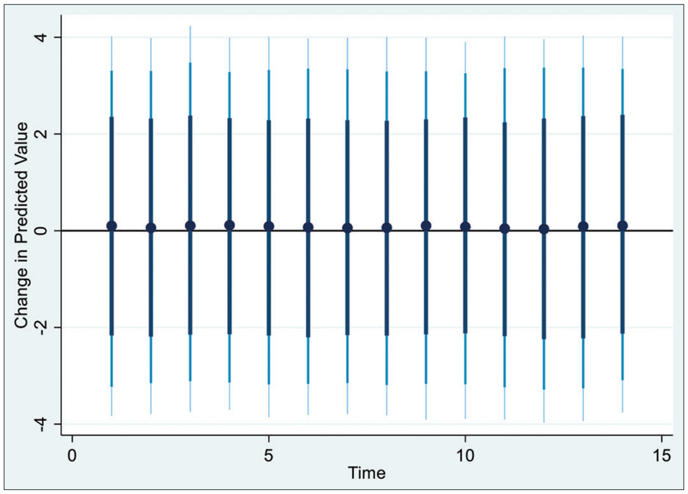
The dynamic ARDL simulation forecast is essential for testing long-term and short-term relationships just like the ARDL time series method. Table 5 shows that the variables HYD, NRE, and GFCF have significant long-term relationships at the 1% level. Where, a 1% increase in HYD, NRE, and GFCF will increase GDP by 0.06%, 0.25%, and 0.23% respectively. Furthermore, L has a significant long-term relationship at the 5% level. A 1% increase in L will increase GDP by 0.41%. Additionally, a 1% increase in L in the short term will increase GDP by 0.38% at the 10% significance level. The long-term relationship of HYD and NRE in dynamic ARDL aligns with the results for ARDL in Table 4. Indirectly, Malaysia also proves that the extension of the Cobb-Douglas theory by Rahman and Velayutham (2020) regarding

Table 5: Dynamic autoregressive distributed lag simulation results

Variables	Coefficient	SE
Short run		
ΔHYDt	0.0565***	0.0186
ΔNREt	0.2528***	0.0669
$\Delta GFCF_{t}$	0.2346***	0.0331
ΔL_{t}	0.4085**	0.1563
ECT_{t-1}	−0.6287***	0.1966
Long run		
HYD_{t-1}	0.0338	0.0304
NRE_{t-1}	0.2218**	0.0853
$GFCF_{t-1}$	0.0763	0.0539
L_{t-1}	0.3853*	0.2063
P>F	0.0000***	
R^2	0.8961	
Root MSE	1.8781	

SE: Standard error, SE: Standard error, GDP: Gross domestic product, HYD: hydropower energy, NRE: non-renewable energy, GFCF: gross fixed capital formation, L: labor, ***, ** and * denote significant level at 1%, 5% and 10%, respectively

Figure 2: Expected shock results in hydroelectric generation using dynamic ARDL simulation. Model of the change (±1%) in the forecast of hydroelectric generation on economic growth (GDP). The dot indicates the average forecast value, and the gradient from dark blue to light blue represents the 75, 90, and 95% confidence intervals.



the relationship between power generation and economic growth is relevant. This simultaneously refutes the Harrod-Domar and Solow-Swan theories that argue that energy is not considered as an input in the production function (Lee and Chang, 2008; Camarero et al., 2015).

Figure 2 shows that a positive shock of 1.5 has a weak positive impact on economic growth. However, negative shocks will cause economic growth to decline. This is consistent with the HYD coefficient value in Table 5. Where, a 1% increase in HYD will increase GDP by a smaller percentage compared to NRE. Not only that, the weak positive impact factor of hydroelectric generation on economic growth in Malaysia can also be clearly seen from Figure 2. Where, electricity generation from non-renewable energy sources is greater compared to renewable energy sources.

The average pointwise marginal effect in Table 6 is equal to the coefficient values expected by linear regression to explain the average marginal effects. Referring to the table above, the average pointwise marginal effects for HYD, NRE, GFCF, and L are 0.03, 0.17, 0.17, and 0.07 respectively. This KRLS test was conducted to test the heterogeneity in marginal effects through the first quartile (P25), the second quartile (P50), and the third quartile (P75) or can be more easily detected using a histogram figure for pointwise marginal effects as shown in Figure 3. Based on this, it is proves that there is no heterogeneity in marginal effects because no covariate section has both positive and negative effects. Therefore, the pointwise derivative of hydroelectric generation on economic growth in Malaysia using the dynamic ARDL method is robust.

Figure 4 is used to examine the variation of long-term terms in hydroelectric power generation and how it affects economic growth or vice versa. Further, it can be used to see the diversity of marginal effects of hydroelectric power generation on economic growth. Referring to Figure 4, the marginal effect is positive when

Figure 3: Distribution of pointwise marginal effect

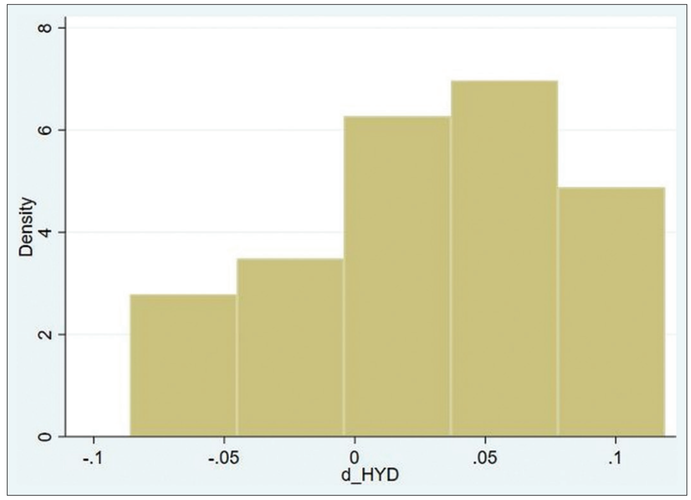


Figure 4: Description of pointwise marginal effect for hydroelectric generation

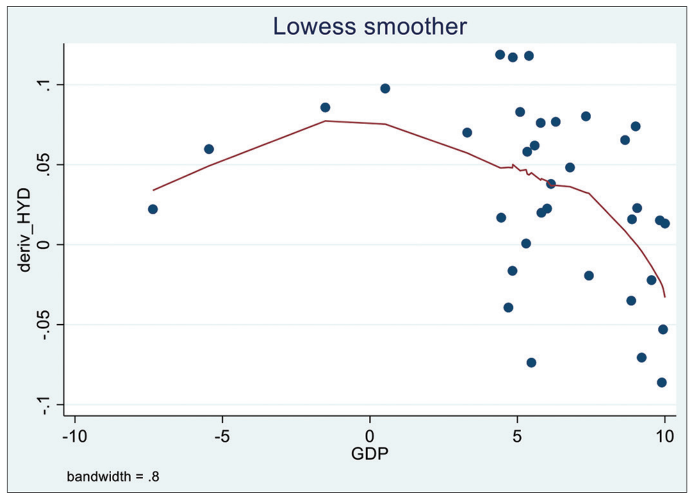


Table 6: Pointwise derivatives from KRLS

GDP	Average	SE	P25	P50	P75
HYD	0.0304***	0.0111	−0.0163	0.0229	0.0761
NRE	0.1714***	0.0373	0.0199	0.2220	0.2921
GFCF	0.1652***	0.0227	0.0165	0.1537	0.2963
L	0.0694	0.1551	−0.1355	0.0374	0.3321
Diagnostic					
Lambda	0.1399	Sigma	4.0000	R^2	0.9305
Tolerance	0.0350	Eff. Df	18.7600	Looloss	80.7800

SE: Standard error, GDP: Gross domestic product, HYD: hydropower energy, NRE: non-renewable energy, GFCF: gross fixed capital formation, L: labor, *** denote significant level at 1%.

GDP values are low. Later, the marginal effect decreases and reaches a negative value at high GDP values. The Environmental Kuznets Curve (EKC) theory explains that as a country's GDP increases, pollution will decrease. This is because more renewable energy sources can be used by a country to reduce greenhouse gas emissions. In Malaysia, Tenaga Nasional Berhad (TNB) is also striving to generate electricity from solar, wind, biomass, and biogas in addition to building dams (Tenaga Nasional Berhad, 2022).

5. CONCLUSION

The issue of increasing greenhouse gases such as sulfur, carbon dioxide, carbon monoxide, methane, and chlorofluorocarbons in the atmosphere from the use of non-renewable energy is a major global concern because these gases can increase the Earth's temperature. Generating electricity from non-renewable energy sources is one of the factors that contribute to the release of greenhouse gases, and Malaysia is a country that still heavily relies on fossil fuels for electricity generation. Therefore, this study was conducted to examine the relationship between hydroelectric power and economic growth in Malaysia. Hydroelectric power is one of the renewable energy sources that can reduce greenhouse gas emissions, thereby reducing the use of dwindling fossil fuels for future generations.

The impact of electricity generation from hydro, electricity generation from non-renewable energy sources, gross fixed capital formation, and labor on the country's economic growth was tested using the ARDL and DYNARDL methods from 1988 to 2022 to detect long-term and short-term relationships for each variable against the country's economic growth. According to the ARDL and DYNARDL methods, HYD and NRE have a positive long-term relationship with GDP. Whereas, all variables have a short-term relationship in the ARDL model. However, the DYNARDL results show that only NRE and L have a short-term relationship with GDP. The regression obtained by both tests in Malaysia is similar to that in China, where previous authors found positive relationship between hydroelectric power and economic growth in China (Li et al., 2023; Ummalla and Samal, 2018).

Given the findings, it is recommended that the Malaysian government intensifies its efforts to transition towards renewable energy sources by providing subsidies for renewable energy projects and revising energy policies to incorporate higher targets for renewable energy. Financial incentives should be offered to industries and businesses to adopt green technologies and reduce reliance on fossil fuels. Additionally, investment in research and development should be prioritized to enhance the efficiency of renewable technologies, particularly in hydroelectric, solar, and wind energy sectors. Public-private partnerships could be mobilized to accelerate the adoption of these technologies and generate economic opportunities in the green technology sector. Through these strategies, Malaysia can not only achieve its economic growth objectives but also contribute significantly to global efforts in reducing greenhouse gas emissions.

This study faces few limitiations such as limited sample size obtained from data sources, especially regarding data on renewable energy sources such as hydroelectric power. The increasing amount of data in the future can improve the sample size that will be used by researchers in the future. Furthermore, it will allow future researcher to take into consideration the use of solar, biomass, and wind as new sources for energy generation in Malaysia. Indirectly, researchers can understand the relationship between the type of renewable energy sources and economic development and environmental protection through the reduction of greenhouse gas emissions.

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