The Impact of Hydropower Energy in Malaysia Under the EKC Hypothesis: Evidence From Quantile ARDL Approach

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Abstract
The present study investigates the impact of economic growth, hydropower generation, and urbanization on Malaysia’s CO₂ emissions. This study applies Quantile Autoregressive Lagged (QARDL) technique for the period of 1965Q1 to 2018Q4. The Granger-causality in quantiles is applied to confirm the causal nexus among the modeled variables. The outcomes demonstrate that hydropower generation decreases the detrimental effects of CO₂ emissions at the range of high quantile levels. Furthermore, urbanization, except for higher quantiles, exhibits negative impacts on CO₂ emissions. Also, the QARDL coefficients confirm the presence of the Environmental Kuznets Curve hypothesis from median to higher quantiles. Besides, the Granger-causality test confirms the two-way causality among CO₂ emissions and hydropower generation in Malaysia’s economy and the same for the other series. The policymakers should enhance the market attractiveness of hydropower generation projects through incentives for the investors.

Keywords
hydropower generation, carbon dioxide emissions, EKC hypothesis; Malaysia

Introduction
In 2020, humanity was crippled by the serious consequences of COVID-19 (coronavirus disease 2019) and amid this, another threat that is climate change, further worsened the impact of the pandemic. This situation called for a serious, and collective response from the global community to tackle the exigencies regarding the global environment (UNCC, 2021). The modern world is embroiling with environmental change issues as a threat to future generations (Awan, Bilgili, & Rahut, 2022; Jahanger et al., 2022). Environmental change is among the significant negative externalities of economic development and industrialization. From an environmental point of view, the environmental change has been caused by deforestation, consuming fossil fuels, and rapid urbanization (El Ouahrani et al., 2011; Usman, Jahanger, Makhdum, et al., 2022). In a recent report by the International Energy Agency, the rise in CO₂ during 1980 to 2015 was documented to increase from 17.78 to 32.1 billion tons (IEA, 2016). In addition, due to economic growth around the world since 2011, the rise in CO₂ emissions was 1.4% (Pérez-Suárez & López-Menéndez, 2015).

In addition, CO₂ emissions is the major contributor to total (greenhouse gases) GHG emissions and is significantly responsible for the rise in global temperature and environmental degradation (Adebayo et al., 2021; Ahmed et al., 2021; Change, 2007; Jahanger et al., 2022). While the main contributor to global CO₂ emissions is the production and consumption of energy which is vital for economic growth (Jahanger et al., 2021; Lotfalipour et al., 2010). Given the importance of environmental degradation, global organizations are emphasizing the member countries to initiate measures for reducing GHG emissions proclaimed in the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto protocols (Höhne et al., 2003; Zhang et al., 2022). In the same vein,
the scientific community is continuously warning about the future threats involved in rising CO₂ emissions. Besides, if GHG emissions are not controlled, they will reach the pre-industrial level by 2035 (Stern, 2007). Against this backdrop, global organizations such as the United Nations call for cutting down global carbon emissions by 45% by 2030 to achieve the target of net zero by 2050 (UNCC, 2021).

On the other hand, reducing GHG emissions which are mainly the result of energy consumption and production is a challenge to governments worldwide. Given its importance in production, industry, and transportation, energy is regarded as vital for economic growth (Apergis & Payne, 2015; Chishti et al., 2020; Jiang, Chishti, et al. 2022; Usman, Jahanger, Radulescu et al., 2022). Furthermore, the consequences of climate change are found negative on economic growth up to 2% to 4% in developing countries till 2040 (Zoundi, 2017). This dilemma of economic growth has been gaining popularity in researchers’ communities. A great deal of literature has been contributed regarding the economic growth and environmental nexus (Awan, Abbasi, et al., 2022). Among the many, the (environmental Kuznets curve) EKC hypothesis is popular in the community of environmental economists to understand the dynamics of economic growth and pollution. Moreover, recent literature on the EKC hypothesis is controlling for energy consumption to suggest environmental protection policies (Bilgili et al., 2016). These studies are using both aggregated and disaggregated energy consumption proxies. Moreover, the literature on disaggregated energy consumption is inserting renewable and nonrenewable energy separately in their models (Hanif et al., 2019; Jiang, Yu, et al., 2022). However, renewable energy is attracting environmental economists due to its environmentally friendly nature (Shahbaz et al., 2015).

Against this backdrop, the extant literature on the environment-energy-growth nexus has put forward many policy-level suggestions to accelerate the transition to lower carbon emissions via renewable energy, nuclear energy, and particularly hydropower. Perhaps, hydropower is the most critical low carbon energy however, it also involves a debate about being environmentally friendly or not. Nevertheless, proponents of hydropower argue that it is eco-friendly being a natural resource (Xiaosan et al., 2021). While the critics think that it should not be perceived as renewable as it put a lot of pressure on nature (Solarin et al., 2017; Usman, Balsalobre-Lorente, Jahanger, et al., 2022). Therefore, it is worthwhile to test the impact of hydropower on environmental degradation. In addition, urbanization is a key factor that affects environmental degradation in the modern world (Pata, 2018). Furthermore, due to urbanization, a rapid energy demand rise in the transport, construction, and manufacturing sectors is observed (Kocoglu et al., 2021). Similarly, with the transformation of society from agro-based economies to modern manufacturing and services-based economies, rural to urban migration is increasing pressure on nature (Shahbaz et al., 2014). This pressure is mainly due to deforestation that results due to new residential areas in the urban area, roads, shopping malls, and park construction (Liu et al., 2018). Therefore, the EKC literature—analyzing the environmental-energy-growth nexus often controls for the effect of urbanization. Furthermore, recent literature analyzing the role of hydropower on the EKC also used urbanization as a control variable (Adebayo et al., 2021).

Nowadays, success in economic development for a country means progress that ensures environmental sustainability integrated into its development policies. Malaysia has been observed as a fast-developing economy since 1957 and is heavily dependent on fossil fuel-based energy (Bekhet & Othman, 2018). The Malaysian economy is expected to progress further, however, the projected demand for energy to meet its future economic progress is a serious challenge to the environment. Malaysia’s commitment to Paris agreement is to reduce GHG by 45% before 2030 however, this would not be an easy target as the country is the second-largest consumer of per capita electricity in the Association of Southeast Asian Nations (ASEAN; Gill et al., 2018). The role of hydropower in Malaysia could help in meeting future energy demand to meet environmental challenges without compromising on economic growth. Malaysia is endowed with palm oil reside, forests, and hydropower to shift on renewable energy production.

With an average growth rate of 4.09 % during 1999 to 2018, CO₂ emissions in Malaysia are significantly increasing over time (Aslam et al., 2021). In addition, Malaysia is one of the fast-developing economies in Asia (Azlina et al., 2014) which transformed from agriculture to a manufacturing-based economy in two to three decades. Moreover, Malaysia is now turning toward a more advanced and services-based economy (Bekhet & Othman, 2018). Besides, Malaysia is targeting an above 4.6% average growth rate till 2030 which requires a huge amount of energy from various sources. Following the tenth 5-year plan (2011–2015), Malaysia has reduced energy intensity by 33%, however, to achieve its environmental goals curbing CO₂ to a higher level is required. In addition, according to recent commitments to a sustainable environment, Malaysia is targeting to reduce GHG emissions intensity by 45% by 2030 as compared to the level in 2005 (UNFCCC, 2015). The graphical trend overall of hydropower generation and CO₂ emissions from 1965 to 2019 are given in Figures 1 and 2, respectively.

Based on the above discussion, the recent paper contributes to the extent literature as follows. Firstly, this is the first study, to the best of our knowledge, on the economy of Malaysia to analyze the role of hydropower and urbanization on CO₂ emissions. Secondly, we prefer to use hydropower generation instead of its consumption considering a new practice in the literature to find more interesting findings, specifically in the case of Malaysia. Thirdly, the recent article deploys the QARDL method since it possesses the ability
to estimate the detailed results to capture the impacts of various independent variables on the dependent side in different quantiles, unlike the previous literature that relies on the conventional techniques that report only an average coefficient of each series. Also, QARDL methods can tackle the issue of potential non-linearity in the series (Godil et al., 2020; Ozturk et al., 2016; Razzaq et al., 2021; Shahbaz et al., 2013). Finally, quantile unit root test and Quantile based Granger causality tests are also applied to divulge detailed and more robust findings.

The remaining part of the paper is organized as follows, the subsequent section discusses the relevant literature about the EKC, hydropower, and urbanization. Section 3 covers the discussion on the data and methodology. Section 4 presents
the result and discussion based on empirical analysis. Finally, Section 5 presents the conclusion and policy implications based on the results.

Literature Review

Though the literature in the context of hydropower, urbanization, economic growth, and environment nexus is enormous, scholars are still of different thoughts about the concrete outcome. Hydroelectricity is also a source of power that either produces less or no pollution. Bildirici and Gökmenoğlu (2017) studied the impact of economic growth, hydropower energy utilization and environmental pollution based on the Markov Switching-Vector Autoregressive (MS-VAR) techniques by employing the panel data of G7 countries from 1961 to 2013. The empirical outcomes show that hydropower energy utilization is a Granger cause of environmental pollution. In another study, Bello et al. (2018) inspected the nexus between hydroelectricity consumption and the environment based on the VECM Granger causality technique. The outcomes revealed unidirectional causality running from hydroelectricity to environmental pollution. Furthermore, Ummalla and Samal (2018) results indicate a bidirectional causality among economic growth, CO₂ emissions and hydropower energy utilization, and a unidirectional causality running from hydropower energy utilization to economic growth. Moreover, Ope Olabiwonnu et al. (2022) outcomes display that impact of Coronavirus (COVID-19) on energy and hydropower with environmental degradation decreased during the pandemic. Additionally, Murshed et al. (2021) empirically found that utilization of coal and oils upsurges environmental degradation while higher utilization of natural gas and hydropower energy utilization is seen to decrease environmental pollution. In a recent study on the top six hydropower energy-consuming countries, Pata and Aydin (2020) results indicate that no evidence was found for a causal relationship between hydropower energy utilization and environmental pollution. Besides, Pata (2018) empirical evidence demonstrated the insignificant effect of renewable energy utilization and hydro energy utilization on environmental degradation. In a recent study, Lau et al. (2016) revealed a one-way causal flow running from hydroelectricity utilization to environmental pollution in the short term. In the long run, the study found causality running from economic growth and hydroelectricity to environmental degradation. Moreover, Xiaoasen et al. (2021) outcomes indicate a one-way causal flow from hydroelectric and renewable electricity to economic growth supporting the energy-led growth hypothesis. Moreover, Solarin et al. (2017) outcome shows that hydroelectricity utilization exerts a long-run adverse influence on environmental degradation. Furthermore, Adebayo et al. (2021) results indicate that hydroelectricity improves the quality of the environment. Therefore, one can observe a conflated role of hydropower in environmental change.

Urbanization is a global phenomenon that is also considered a major cause of economic growth. Half of the world’s population exists in urban zones (Al-Mulali et al., 2019; Chien et al., 2022; Rafindadi & Ozturk, 2015; Solarin & Ozturk, 2015). Typically, unemployed people move from rural to urban areas for employment opportunities; this movement interrupts the environment in urban areas. Rahman and Alam (2021) revealed that urbanization triggers environmental pollution while hydroelectricity energy utilization improves the quality of the environment. Yasin et al. (2021) have scrutinized the nexus between financial development, urbanization, energy utilization, and the environment. The study finds that financial development, urbanization, and energy utilization deteriorate environmental pollution. Nathaniel et al. (2021) findings reveal that a feedback causality exists between economic growth, globalization, urbanization, and environmental degradation. Interestingly, the majority of the existing literature focused on the impact of urbanization has reported positive evidence in various contextual settings. For example, Mignonissy and Djeufack (2021), Anwar et al. (2021), Nathaniel (2021), Wang et al. (2022), Nathaniel et al. (2020), Ahmed et al. (2020), Ali et al. (2019), and Anwar et al. (2020) studied the impact of urbanization on the environment and reported a positive influence of urbanization on the environment. Whereas, Ulucak and Khan (2020) reported a negative impact of urbanization on environmental quality. Since the seminal study of Grossman and Krueger (1991), many empirical investigations have been conducted to analyze the association between economic growth and environmental pollution. For example, Jebli et al. (2016), Al-Mulali et al. (2015), Alam et al. (2016), Apergis and Ozturk (2015), Gao et al. (2021); Bibi and Jamil (2021), Katircioğlu (2014), Al-Mulali et al. (2016), Yang et al. (2021), Usman and Jahanger (2021), Dogan and Inglezis-Lotz (2020), Leal and Marques (2020), Saint Akadırı et al. (2021), Adefaraoq et al. (2020), Bekun et al. (2021), Tenaw and Beyene (2021), Balsalobre-Lorente et al. (2021), Jahanger (2021), and Genç et al. (2022) have all validated the EKC hypothesis. However, others such as Pata and Caglar (2021), Solarin and Lean (2016), Ozturk and Al-Mulali (2015), Tan et al. (2014), Chandran and Tang (2013), Yilanci and Pata (2020), and Koc and Bulus (2020) have failed to validate the EKC hypothesis. To document a review of those studies related to Malaysia and other developing countries, Table 1 summarizes studies related to hydroelectricity and other factors in combating environmental pollution.

Based on the aforementioned literature review, it is apparent wherein the nexus between CO₂ emissions, GDP per capita, hydropower generation, and urbanization had been studied, the results are yet inconclusive. Additionally, the majority of the prior studies consider the linearity of the modeled series, while ignoring the asymmetries. Hence, this literature gap endorses investigating the asymmetric nexus of hydropower generation, urbanization, and CO₂ emission while applying the QARDL method.
Theoretical Framework, Data, and Methodology Framework

Theoretical Framework
The Environmental Kuznets Curve (EKC) hypothesis reflects the disclosure of an income inflection point in environmental quality changes, that is, the trend of environmental quality deterioration first after improvement with the income rise. The model assumes that there are three main structures: linear, quadratic, and cubic functions.

\[
CO_{2i} = \beta_{0i} + \beta_1 Y_{it} + \epsilon_{it},
\]

(1)

\[
CO_{2i} = \beta_{0i} + \beta_1 Y_{it} + \beta_2 (Y_{it})^2 + \epsilon_{it},
\]

(2)

\[
CO_{2i} = \beta_{0i} + \beta_1 Y_{it} + \beta_2 (lnY_{it})^2 + \beta_3 (lnY_{it})^3 + \epsilon_{it}.
\]

(3)

In equation (3) all parameters (i.e., \( \beta_1, \beta_2, \) and \( \beta_3 \)) of economic growth \( (Y) \) demonstrate the functional form of the EKC hypothesis. Where, \( \beta_0 \) represents the constant term and the term \( \epsilon_{it} \) displays the error term, \( i \) and \( t \) symbolize the cross-section (countries). The functional form is presented in Table 2 and Figure 3, there are seven possible cases in which the EKC curve changes its shape. For example, Case 1 display that the coefficients of all series have zero which indicates no relationship exists between \( CO_2 \) emissions and \( Y \). On the other hand, Cases 2 and 3 shows the increasing or decreasing relationship between \( CO_2 \) emissions and \( Y \). Additionally, Cases 4 and 5 embodies the U-shaped and inverted U-shaped existence between \( CO_2 \) emissions and \( Y \).

Methodology Framework
The recent study follows the following strategy to perform econometric analysis. Firstly, we deploy the quantile unit

| Study                  | Data       | Countries | Variables          | Methodology                        | Findings                                      |
|------------------------|------------|-----------|--------------------|------------------------------------|-----------------------------------------------|
| Ummalla and Samal (2018) | 1965–2016  | China     | \( CO_2, Y, \) and HEC | ARDL bound test,                   | EKC is invalid. CO\(_2\) has a positive influence on HEC |
| Xiaosan et al. (2021)   | 1990–2018  | China     | Hydel, RENE, GENI, FDI, \( Y \), and \( CO_2 \)| ARDL and Granger causality test | Hydel, RENE, and GENI lower \( CO_2 \), \( Y \), and FDI enhance environmental degradation. |
| Lau et al. (2016)       | 1965–2010  | Malaysia  | HEC, \( Y, \) and \( CO_2 \)| Granger causality                  | \( Y \) and HEC granger cause \( CO_2 \) in the long run, however, HEC granger causes \( CO_2 \) in the short run. |
| Babatunde et al. (2021) | 2015–2050  | Malaysia  | NGS, \( CO_2 \), and ENG | Input and output model             | NGS stimulates excessive ENG, and thus phasing it out would reduce environmental degradation |
| Bildirici and Gökmenoğlu (2017) | 1961–2013 | G7 countries | HEC, \( Y, \) and \( CO_2 \) | MSVAGC approach                   | HEC causes \( Y \) in overall, and two-way causation in some G7 economies. |
| Pata and Aydin (2020)   | 1965–2016  | Top six hydropower consuming economies | HEC, EFP, REN, \( Y \), and \( CO_2 \) | ARDL                              | No causal association between HEC and EFP was found. The EKC is invalid for Brazil, China, Canada, India, Norway, and the US |
| Sinaga (2019)           | 1978–2016  | Malaysia  | HEC and \( Y \) | ARDL                              | HEC reduces environmental degradation. |
| Bilgili et al. (2021)   | 1980–2019  | USA       | HYDEC and \( CO_2 \) | CWT approach Continuous Wavelet transformation | In the short run, HYDEC intensifies environmental degradation, however, in long run, it reduces. |
| Pata (2018)             | 1974–2014  | Turkey    | \( CO_2, Y, \) FDI, REN, URB, and HYDEC | ARDL and FMOLS                     | HYDEC and REN do not affect \( CO_2 \). EKC is valid. |
| Pata and Kumar (2021)   | 1980–2016  | China and India | FDI, HEC, coal, \( CO_2 \), and HYDEC | ARDL                              | HEC upsurges \( CO_2 \) and EFP for China but no influence on India. |
| Bello et al. (2018)     | 1971–2016  | Malaysia  | EFP, \( CO_2 \), \( Y \), and \( HEC \) | ARDL                              | HEC has a negative effect on environmental pollution. |
| Tiwari et al. (2022)    | 1971Q1 to 2017Q4 | Brazil and China | Hydro, EF, urban, and human capital | QARDL                            | Hydropower mitigates pollution. |
root test to confirm the data properties of the series involved in the study. Subsequently, the QARDL method is applied to obtain the long-run and short-run coefficients. In addition, the present study used the Wald test to check the parameters’ constancy. Lastly, we deploy the quantile-based Granger causality test to affirm the quantile-wise causality to recommend the policies. Figure 4 explains the econometric framework adopted by the present study.
Quantile autoregressive unit root test. Firstly, we checked the stationarity properties of the data series by employing the Quantile Autoregressive (QAR) unit root test. The QAR unit root test proposed by Koenker and Xiao (2004) and later extended by Galvao (2009) is used to test the stationarity of time series data on all quantiles of conditional mean and conditional distribution. The QAR unit root test is based on the following conditional quantile autoregression model:

\[ Q_{it}(ρ|W_{t-1}) = \beta_0(ρ) + \beta_1(ρ) r_{t-1} + \sum_{j=1}^{p} \beta_{j+1}(ρ) \Delta r_{t-j}, \]  

where, \( Q_{it}(ρ|W_{t-1}) \) is the conditional quantile of \( r_{t} \) for a quantile level \( ρ \in (0,1) \) and \( W_{t-1} \) is the information accumulated up to time \( t-1 \). For a given level of a single quantile, the null hypothesis for the unit root can be expressed as \( H_0: β_1(ρ) = 1 \) for a given \( ρ \). The estimation of the coefficients of the above equation can be obtained by quantile regression, as shown below:

\[ \hat{β}(ρ) = \arg \min_{β} \sum_{t=1}^{T} \varnothing_t (r_t - x_t β), \]  

where \( β \) and \( x_t \) are defined as \( β = (β_0(ρ), β_1(ρ), ..., β_{p+1}(ρ)) \) and \( x_t = (1, r_{t-1}, Δr_{t-1}, ..., Δr_{t-p})' \), respectively. Based on Koenker and Bassett (1978), \( \varnothing_t(υ) = υ(ρ - I(υ < 0)) \). The null hypothesis is defined as non-stationary that requires \( ρ \in T \). To test the null hypothesis, Koenker and Xiao (2004) proposed a \( t \)-ratio statistic:

\[ t_{p}(ρ) = \frac{\hat{f}(F^{-1}(ρ)) (Y_{t-1} - P_{t-1} Y_{t-1})^{\frac{1}{2}} (\hat{β}_{-1}(ρ) - 1)}{\sqrt{p(1-ρ)}}. \]

where, \( \hat{f}(F^{-1}(ρ)) \) is \( f(F^{-1}(ρ)) \)'s consistent estimator, with \( f \) and \( F \) are density and distribution functions of \( υ_t \) in equation (4), respectively. \( Y_{t-1} \) is representing the vector of lagging dependent variables. Besides allowing for asymmetric effects of shocks on carbon emissions an important advantage of QAR-based unit root tests over standard unit root tests is that they have more power (Koenker & Xiao, 2004).

Quantile autoregressive distributed lagged approach. To study the quantile dynamics between carbon emissions, economic growth, hydro generation, and urbanization of Malaysia, we applied the novel Quantile Autoregressive Distributive Lagged (QARDL) model intended by Cho et al. (2015). The QARDL model is more detailed and advantageous than the linear model. Firstly, this model investigates the nonlinear association between all the study variables compared to the traditional method of focusing on the linear association through mean regressed outcomes. This model can be used to test the long-term quantile equilibrium effects of economic growth, hydro power generation and urbanization on carbon emissions. Secondly, the QARDL model is an advanced form of the “ARDL model,” through which expected asymmetries between economic growth, hydropower, urbanization, and carbon emissions can be analyzed. Based on this, the QARDL model becomes most suitable for the nonlinear and asymmetric relationship of economic growth, hydropower, and urbanization with carbon emissions in Malaysia. The basic form of linear ARDL is as follows:

\[ Co_{2t} = μ + \sum_{i=0}^{p} δ_{i} Co_{2r-i} + \sum_{i=0}^{p} ξ_{i} Y_{t-i} + \sum_{i=0}^{p} ζ_{i} Y^2_{t-i} \]

\[ + \sum_{i=0}^{p} δ_{i} hydroG_{t-i} + \sum_{i=0}^{p} ζ_{i} urban_{t-i} + e_{t}, \]  

where in above equation (7), \( e_t \) indicates the error(residual) terms which are described through \( \{ Y_t, Y^2_t, hydroG_t, UR_t, Y_{t-1}, Y^2_{t-1}, hydroG_{t-1}, UR_{t-1}\} \) and \( p_1, p_2, p_3 \), and \( p_4 \) are lag orders indicated by the Schwarz information criterion (SIC). Moreover \( Co_{2t}, Y_t, Y^2_t, hydroG_t, UR_t \) state to the natural logarithm series of carbon emissions, economic
growth, economic growth square, hydropower generation, and urbanization discretely.

The model shown in equation (7) was further extended by Cho et al. (2015) which provide a good concept of QARDL \((\alpha, \rho)\) form as under:

\[
QCo_{2t} = \mu(t) + \sum_{i=1}^{\alpha} \varrho_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \varphi_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \varphi_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \varepsilon_i (\gamma(t)) \tag{8}
\]

In above equation (8), the term \(\varepsilon_i (\gamma(t)) = Co_{2t} - QCo_{0t} \left( \frac{\tau}{\varepsilon_i (\gamma(t))} \right) \) (Kim & White, 2003) and \(0 > \tau < 1\) shows quantile. This paper used the following set of quantiles \(t\) lies to \(\{0.0, 0.1, 0.2, 0.3, 0.4 \ldots 0.9\}\) for the analysis data. Moreover, due to the reason that anticipated probability of serial correlation in equation (8), the QARDL model is further rebuilt as follows:

\[
Q\Delta Co_{2t} = \mu + \delta_{\text{re}} Y_{t-i} + \delta_{\text{null}} Y^2_{t-i} + \delta_{\text{UR}} Y^2_{t-i} + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \varepsilon_i (\gamma(t)) \tag{9}
\]

In addition, the above equation (9) can be reformulated (Cho et al., 2015) to give the QARDL-ECM model:

\[
Q\Delta Co_{2t} = \mu (\gamma(t)) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \sum_{i=0}^{\rho} \sigma_i (\gamma(t) Y_{t-i}) + \varepsilon_i (\gamma(t)) \tag{10}
\]

By using the \(\Delta\) method, the cumulative short-term influence of foregoing carbon emissions has been computed through \(\varepsilon^* = \sum_{j=1}^{\alpha} \varepsilon_j\), while the cumulative short-term impact of the previous and current levels of \(Y, Y^2\), hydroG, and urban is determined by \(\gamma^* = \sum_{j=1}^{\alpha} \varepsilon_j\). Furthermore, the parameter related to long-run cointegration for \(Y, Y^2\), hydroG, and Urban as

\[
\omega_{\text{UR}} = \frac{\omega_{\text{hydroG}}}{\rho}, \quad \omega_{\text{hydroG}} = \frac{\omega_{\text{hydroG}}}{\rho}, \quad \omega_{\text{hydroG}} = \frac{\omega_{\text{hydroG}}}{\rho}, \quad \omega_{\text{urban}} = \frac{\omega_{\text{urban}}}{\rho}, \quad \omega_{\text{urban}} = \frac{\omega_{\text{urban}}}{\rho}, \quad \omega_{\text{urban}} = \frac{\omega_{\text{urban}}}{\rho},
\]

Quantile Granger-causality test. In addition, the Quantile Granger-causality test is observed, which was developed by Troster (2018) to analyze the causality of quantiles among carbon emissions, economic growth, hydropower generation and urbanization in Malaysia. Meanwhile, Granger (1969) assumes a specific variable \(Y\) does not cause another variable, such as \(X_i\), has not hypothesized to approximate \(X_i\), in accordance with the foregoing \(X_i\).

For this purpose, it is assumed under the present study that there is an explained vector \(G_i = G_i^{X}, G_i^{Y} \in R^k, a = \alpha + r\),

where \(G_i^{X}\) the precious group of \(G_i^{Y} = (G_i^{X}, \ldots, r) \in R^r\). Moreover, our research explains the null hypothesis of non-Granger Casualty from \(Y\) to \(X_i\) as follow:

\[
H_{0}^{X \rightarrow Y} : F_{X} \left(G_i^{X}, G_i^{Y} \right) = F_{X} \left(G_i^{X} \right), \text{ for all } x \in R \tag{11}
\]

Under the null hypothesis from equation (8), \(F_{X} \left(G_i^{X}, G_i^{Y} \right)\) represents the interim distribution motive of \(X_i\), giving \(G_i^{X}, G_i^{Y} \). Consistent with (Granger, 1969), this research used the \(D_i\) check by put in order the QAR approach \(n(t)\) for all \(0 \in \mathbb{R}\), depending on the null hypothesis of non-Granger Casualty is as follow:

\[
\text{QAR} \left(1\right): n(t) \left(G_i^{X}, \sigma(\delta) \right) = \tau_1 (\delta) + \tau_2 (\delta) Y_{t-1} + \mu r^{-1}_1 (\delta), \tag{12}
\]

where, the coefficient \(\sigma(\delta) = \tau_1 (\delta), \tau_2 (\delta)\) and \(\mu\) approximated by the highest probability in the same point of quantiles, and \(r^{-1}_1 (\delta)\) means the inverse of the standard basic distribution function. To identify the manifestation of causality between variables, we established the QAR method of equation (11) with lagged to alternative factor. Finally, the equation of QAR (1) reconstructing is as follow:

\[
Q_{\infty}^{X} \left(G_i^{X}, G_i^{Y} \right) = \tau_1 (\delta) + \tau_2 (\delta) X_{t-1} + \sigma(\delta) Y_{t-1} + \mu r^{-1}_1 (\delta). \tag{13}
\]
Data and Descriptive Statistics

In this present study, we empirically inspect the role of hydro generation, economic growth, and urbanization on CO₂ emissions in the EKC hypothesis background from 1965 to 2018 for Malaysia’s economy. To this end, we use carbon emissions (CO₂), Hydropower generation (hydroG), economic growth (Y), and Urbanization (urban). The CO₂, hydroG data are taken from British Petroleum (BP, 2020). On the other hand, the data for GDP and urbanization are attained from the World Development Indicators (WDI, 2020). Annual data is converted into quarterly data using the quadratic match sum method following Godil et al. (2020) and finally, converted into a natural log form. A detailed description of the variables is presented in Table 3.

Table 3. Variable Description and Data Sources.

| Variables          | Acronyms | Measurement units                                      | Data sources   |
|--------------------|----------|-------------------------------------------------------|----------------|
| Carbon emissions   | CO₂      | Carbon emissions (metric tons per capita)             | BP (2020)      |
| Hydropower generation | hydroG  | Twh                                                   | BP (2020)      |
| Economic growth    | Y        | GDP Constant 2010 US dollars                          | WDI (2020)     |
| Urbanization       | Urban    | urban population as % of the total population         | WDI (2020)     |

Note: WDI = World Bank indicators.

Table 4. Descriptive Statistics.

| Variable    | M        | SD       | Minimum  | Maximum  | Jarque B. | p-Value |
|-------------|----------|----------|----------|----------|-----------|---------|
| LnCO₂       | 0.5040   | 0.3073   | -0.1669  | 0.8897   | 18.6600   | .0000   |
| LnhydroG    | 0.5413   | 0.4394   | -0.2314  | 1.4289   | 14.7000   | .0000   |
| LnY         | 10.9403  | 0.4211   | 10.1875  | 11.5826  | 7.6400    | .0200   |
| Lnurban     | 1.7065   | 0.1250   | 1.4759   | 1.8810   | 15.8100   | .0000   |

Data and Empirical Results

Empirical Results and Interpretation

In this study, at different quantiles, Table 5 indicates the findings of the unit root test for which the quantile unit root test was used. The findings indicate that data is non-stationary at the level but not at all quantile levels. Consequently, the mixed results of unit root properties validate the use of the QARDL model (Godil et al., 2020). The QARDL model can be used to series regardless of whether they are I(0), I(1) (Sharif et al., 2020). It is evident from the outcomes that the test qualifies the data for the application of QARDL.

Table 6 shows the outcomes for the Quantile autoregressive distributive lag. The findings for the QARDL model estimation are provided in Table 6 for Malaysia’s carbon dioxide emissions. It is expressed that the estimated parameter θ * is observed as negatively significant. This parameter shows the speed of adjustment, the negative and significant sign of this parameter shows that there is long-term equilibrium reversion in these quantiles between dependent and independent variables. This outcome is observed across the quantiles (0.0, 0.2, 0.6, 0.8, 0.9, and 0.95) in Malaysia, indicating the fact that there is a reversion to the long-term equilibrium association between carbon emissions and independent variables. The findings show that economic growth ωY is significantly positive at the median and above the median level of quantile distribution (0.60–0.95) quantiles, while the square of economic growth ωY² is significantly negative at the quantile level 0.50 to 0.95. The long-term cointegrating parameter ωGDPs indicates that there is a positive effect of economic growth on the CO₂ emissions, however, the relationship is significant at higher carbon emissions levels (0.60–0.95 quantiles), while insignificant for lower quantile levels (0.05–0.40 quantiles). The negative sign of ωY² confirms the existence of the inverted U-shaped EKC hypothesis from moderate to higher quantile levels (0.50–0.95 quantiles). This finding extends the previous studies in this domain (Adeel-Farooq et al., 2020; Bibi & Jamil, 2021; Dogan & Inglese-Lotz, 2020; Leal & Marques, 2020; Saint Akadiri et al., 2021; Usman & Jahanger, 2021). In addition, our results are in line with the prevailing literature by Mikayilov et al. (2019), Al-Mulali et al. (2016), and Pata and Aydin (2020).
Hydropower generation \( \omega_{HG} \) produces significant negative effects on \( \text{CO}_2 \) emissions and coefficients in the range of higher quantile levels (0.70, 0.80, and 0.95) and insignificant effects at lower quantiles (0.05–0.60). This indicates that Hydro generation (\( \text{hydroG} \)) mitigates \( \text{CO}_2 \) emissions only at the higher quantile levels (0.70, 0.80, and 0.95 quantiles) and the negative sign shows that as \( \text{hydroG} \) increases at a higher pace in Malaysia; it will reduce the emission of \( \text{CO}_2 \) emissions. The coefficient of \( \text{hydroG} \) is negative at a lower carbon emissions level (0.10–0.60) however shows an insignificant effect. The result of the negative impact of hydropower on environmental pollution demonstrates that this is an environment-friendly energy source and it can enhance the quality of the environment in Malaysia. Investment in the hydropower projects in Malaysia, in the start, does not show a significant effect but later it shows the significant effects on reducing the \( \text{CO}_2 \) emissions. It means the investment in hydro power projects shows the effects after some lags, as shown by higher quantiles of QARDL. These results are consistent with the result of Bello et al. (2018). Malaysia has a lot of natural hydro resource potential and approximately 189 rivers with a length of around 57,300 km (Hossain et al., 2018; Tang et al., 2019) and \( \text{hydroG} \) contributed around 14% of total Malaysian power generation and installed hydropower capacity of 6,275 (MW) which is the seventh biggest hydropower capacity all over the world according to the Hydropower Status Report (HSR, 2021). Furthermore, it is noticeable that the \( \text{CO}_2 \) emission reduction effect of hydropower is increased from 0.00763% to 0.0264% with a rising in emissions level from 0.70 to 0.95 quantiles. This segment of results might suggest significant insights regarding the role of hydropower in Malaysia. Malaysia should adopt eco-friendly technologies and invest in the energy efficiency of power generation, particularly hydro-based power generation sources. Further, our results

**Figure 5.** Box plot summary statistics of our key variables: (a) \( \ln\text{CO}_2 \), (b) \( \ln\text{hydroG} \), (c) \( \ln\text{urban} \), and (d) \( \ln Y \).
confirm an asymmetric long-run association between CO$_2$ emissions and Hydro generation. In addition, following the literature on Risk theory, environmental risks from increased consumption of polluting energy sources might be disturbing in the future (Carvalho & Almeida, 2011). Moreover, hydropower provides cheap and zero carbon based energy to the growing requirement of growing energy demand by transforming society from rural to urban.

Urbanization, $\omega_{urban}$, is positive and significant primarily at low-high (0.10–0.70) quantiles. These findings represent that urbanization (urban) significantly contributes to the CO$_2$ emissions level in the case of Malaysia. In the context of urban transition theory, it can be argued that while people migrate from rural to urban areas, urbanization surges the consumption of energy and CO$_2$ emissions (Kocoglu et al., 2021; Tiwari et al., 2022). This piece of evidence shows that the urbanization pattern in Malaysia is environmentally unsustainable, as rising pressure on the urban infrastructure is reflected in terms of the rising CO$_2$ emissions. The percentage of the urban population in Malaysia has been continuing to increase to approximately 65% in 2010 and around 75% in 2020 and Malaysia’s population will reach around 33.9 million in 2040 and 85% population will be residents in urban areas (Samat et al., 2020). The growth of the urban population, enhance the demand for electrical accessories/appliances (i.e., ventilation, cooking, lighting, etc.) contributed to increased environmental degradation. The Malaysian government has encouraged national and international investors to contribute to industrialization activities with eco-friendly technologies, mostly in urban areas. These results are in line with the findings of Bekhet and Othman (2017). On the other hand, short-term dynamics depict that the current emissions of CO$_2$ emissions are positively and significantly affected by their preceding levels at all the quantile levels. The contemporary and earlier variations in $Y$ have a negative significant influence only at the low level (0.05–0.10) of quantiles, while, $Y^3$ has a positive significant impact on current emissions of CO$_2$ at low quantiles (0.05–0.10). Moreover, the preceding and current variations in Hydro generation and urbanization have no significant influence on contemporary carbon emissions in the short run. The summary of parameters estimated through the QARDL is depicted in Figure 6 and the graphical presentations of empirical findings are presented in Figure 7.

Along with the presentation of the results, it is necessary to evaluate the dynamic stability of the empirical model. The results of the Wald test in Table 7 show that the null hypothesis of linearity (i.e., parameter constancy) for the speed adjustment parameter is rejected in Malaysia. In addition, for hydropower generation, the null hypothesis of linearity across different tails of every quantile for long-term parameters among variables that are under consideration is rejected.

| Table 5. Results of Quantile Unit Root Test. |
|-----------------------------------------------|
| $Y$                                           |
| $t$  | Critical values | $\alpha$ (persistent parameter) | $T$  | Critical values | $\alpha$ (persistent parameter) | $T$  | Critical values | $\alpha$ (persistent parameter) | $T$  | Critical values | $\alpha$ (persistent parameter) |
|------|----------------|-------------------------------|------|----------------|-------------------------------|------|----------------|-------------------------------|------|----------------|-------------------------------|
| -0.426 | -3.1533 | .9694 | .2374 | -2.3402 | 1.0097 | -0.0441 | -2.3100 | .9977 | -0.2781 | -2.5537 | .9799 |
| -1.032 | -3.3827 | .9661 | -0.8872 | -2.9374 | .9734 | -1.5036 | -2.5104 | .9991 | -0.101 | -3.0055 | 1.0047 |
| -1.2883 | -3.41 | .9736 | -1.0949 | -3.3098 | .9823 | -2.6373 | -2.7497 | .9992 | -0.1425 | -2.2512 | .9666 |
| -0.6493 | -3.41 | .9898 | -1.2881 | -3.31 | .9812 | -0.3866 | -2.8954 | .9995 | 0.3078 | -3.41 | 1.0054 |
| 0.0495 | -3.41 | 1.0007 | -0.8644 | -3.41 | .9876 | -0.2119 | -3.0819 | .9997 | 0.6805 | -3.41 | 1.0091 |
| 0.4037 | -3.41 | 1.0047 | -1.3053 | -3.41 | .9816 | 2.4245 | -3.1805 | 1.003 | 0.675 | -3.41 | 1.0077 |
| 0.7293 | -3.41 | 1.0076 | -0.3248 | -3.41 | .9957 | 4.5415 | -3.2632 | 1.007 | 0.2176 | -3.41 | 1.0024 |
| 1.2103 | -3.41 | 1.01 | -1.0353 | -3.41 | .9857 | 4.2326 | -3.2442 | 1.0068 | 0.5 | -3.41 | 1.0051 |
| 0.3572 | -3.41 | 1.0027 | -0.6588 | -3.41 | .9906 | 3.9463 | -3.357 | 1.0066 | -0.7541 | -3.41 | 1.0092 |
| 0.3672 | -3.41 | 1.0026 | -0.962 | -3.41 | .987 | 2.9713 | -3.41 | 1.007 | -0.9728 | -3.41 | 1.0095 |
| 0.8443 | -3.41 | 1.0057 | -0.6062 | -3.41 | .9925 | 3.5609 | -3.41 | 1.0073 | -1.2345 | -3.41 | 0.98 |
| 0.484 | -3.41 | 1.0033 | -1.3 | -3.41 | .985 | 2.6762 | -3.41 | 1.0063 | -1.863 | -3.41 | 0.9821 |
| 0.3637 | -3.41 | 1.0025 | -1.3401 | -3.41 | .9836 | 2.4274 | -3.41 | 1.0067 | -2.1367 | -3.41 | 0.9795 |
| 0.2672 | -3.41 | 1.0016 | -0.6508 | -3.41 | .9913 | 3.9299 | -3.41 | 1.0124 | -2.3421 | -3.41 | 0.9735 |
| 0.2288 | -3.41 | 1.0022 | -0.439 | -3.41 | .9929 | 5.5846 | -3.41 | 1.0181 | -2.3063 | -3.41 | 0.9705 |
| 0.0808 | -3.2856 | 1.001 | -0.4497 | -3.41 | .9917 | 5.252 | -3.41 | 1.0193 | -2.3743 | -3.41 | 0.9655 |
| -0.1351 | -2.9977 | .9975 | -0.014 | -3.41 | .9997 | 6.5889 | -3.3713 | 1.0209 | -1.5153 | -3.2937 | 0.9659 |
| -0.4338 | -2.4661 | .9849 | -0.6075 | -3.41 | .9771 | 5.9319 | -3.2232 | 1.0231 | -1.0838 | -3.1811 | 0.9363 |
| -1.1756 | -2.3589 | .9573 | -0.1754 | -3.3537 | .9786 | 2.8881 | -3.0019 | 1.0276 | -0.8282 | -2.6826 | 0.933 |

Note. This table shows point estimates and $t$-statistics values for the 5% significance level and the critical value. If the $t$-statistic is numerically smaller than the critical value, we reject the null hypothesis of $\mu (T) = 1$ at the 5% level. Bold values of $t$-statistics denote rejected of the null hypothesis at the 5% significance level.
Table 6. Results of Quantile ARDL for Malaysia.

| Variables | (1)    | (2)    | (3)    | (4)    | (5)    | (6)    | (7)    | (8)    | (9)    | (10)   | (11)   |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| $\theta$  | $0.00270 (0.0383)$ | $-0.05360 (0.0305)$ | $-0.03589** (0.0116)$ | $-0.02977*** (0.0112)$ | $-0.02993 (0.0145)$ | $-0.03923** (0.0172)$ | $-0.04023** (0.0186)$ | $-0.0117** (0.0142)$ | $-0.0348** (0.0142)$ | $-0.03270 (0.0284)$ | $-0.1311*** (0.0470)$ |
| $\gamma$  | $-0.175 (0.291)$ | $0.0030 (0.126)$ | $0.0009 (0.160)$ | $0.111 (0.113)$ | $0.108 (0.108)$ | $0.158 (0.106)$ | $0.231* (0.120)$ | $0.354*** (0.115)$ | $0.499** (0.175)$ | $0.463* (0.231)$ | $1.007*** (0.326)$ |
| $\gamma^2$| $0.00207 (0.0252)$ | $-0.00132 (0.0047)$ | $-0.00188 (0.0028)$ | $-0.00281 (0.0020)$ | $-0.00350** (0.0019)$ | $-0.00109 (0.0022)$ | $-0.00141 (0.0021)$ | $-0.00037 (0.0030)$ | $-0.00019 (0.0035)$ | $-0.00043 (0.0042)$ | $-0.00198*** (0.0057)$ |
| hydroG    | $0.00456 (0.0518)$ | $-0.00096 (0.0079)$ | $-0.00096 (0.0094)$ | $-0.00109 (0.0032)$ | $-0.00257 (0.0034)$ | $-0.00077 (0.0041)$ | $-0.00076 (0.0056)$ | $-0.00017 (0.00475$ | $-0.00013 (0.0052)$ | $-0.00013 (0.0014)$ | $-0.00012 (0.0016)$ |
| urban     | $0.221 (0.664)$ | $0.324*** (0.117)$ | $0.326*** (0.093)$ | $0.317** (0.079)$ | $0.300*** (0.072)$ | $0.297** (0.056)$ | $0.300** (0.069)$ | $0.308 (0.133)$ | $0.199 (0.206)$ | $0.200 (0.206)$ | $0.200 (0.206)$ |
| $\phi$    | $-0.804*** (0.121)$ | $0.553*** (0.0812)$ | $0.465*** (0.065)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ | $0.475*** (0.0572)$ |
| $\delta_{d_1}$ | $-4.206*** (1.996)$ | $-7.328** (4.310)$ | $-3.144 (3.927)$ | $-0.879 (4.998)$ | $-1.312 (4.436)$ | $-1.014 (4.053)$ | $-2.621 (4.753)$ | $-1.663 (4.753)$ | $-0.870 (4.946)$ | $-1.903 (5.907)$ | $-4.204 (4.705)$ |
| $\delta_{d_2}$ | $-0.103** (0.029)$ | $0.161 (0.133)$ | $0.066 (0.093)$ | $0.063 (0.083)$ | $0.030 (0.074)$ | $0.030 (0.074)$ | $0.030 (0.074)$ | $0.030 (0.074)$ | $0.030 (0.074)$ | $0.030 (0.074)$ | $0.030 (0.074)$ |
| $\delta_{durban}$ | $-4.635 (3.480)$ | $-2.546 (4.447)$ | $0.125 (2.728)$ | $1.055 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ | $1.097 (2.608)$ |
| $\delta_{hydroG}$ | $-0.0165 (0.9360)$ | $-0.00074 (0.0328)$ | $-0.00004 (0.0251)$ | $0.00014 (0.0279)$ | $0.00092 (0.0245)$ | $0.0131 (0.0246)$ | $0.0311 (0.0285)$ | $0.0437 (0.0363)$ | $0.0235 (0.0476)$ | $0.0235 (0.0476)$ | $0.0235 (0.0476)$ |
| Constant  | $2.425 (3.769)$ | $-0.662 (3.396)$ | $-0.530 (2.023)$ | $-1.478 (4.247)$ | $-1.465 (3.919)$ | $-2.173 (3.936)$ | $-3.044 (4.111)$ | $-6.966*** (1.529)$ | $-6.477** (2.211)$ | $-5.649* (2.949)$ | $-14.61*** (4.169)$ |
| Observations | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ | $218$ |

Note. This table reports the quantile estimation results. The standard errors are between brackets. $***$, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.
Figure 6. Parameters estimate of QARDL at quantile 0.05 to 0.95, with red dotted lines showing significance level at 95% CI.

Figure 7. Graphical presentation of empirical findings.
Lastly, the cumulative short-term influence of urbanization is asymmetric (non-linear) at a 5% significance level individually across quantiles.

Table 8 reveals the empirical findings of the quantile causality test. The main findings describe that there exists a two-way causality running among CO2 emissions and hydroG because all critical values are rejected at 1% significance level, (except at quantile 0.5). These results are supported by the previous findings of Bildirici and Gökmenoğlu (2017). Moreover, the CO2 emissions and Y also have a two-way causality with urban as indicated by the results of the quantile causality test. These results are in line with the findings of Ummalla and Samal (2018). The other two variables (hydroG and Y) also have mutual causality which is in line with our long-term results (except at the median quantile level of 0.5).

Table 7. Results of the Wald Test.

| Variables     | Wald test (p-value) |
|---------------|---------------------|
| ρ             | 6.05*** (.000)      |
| y             | 8.02 (.6232)        |
| Y^2           | 9.43 (.4961)        |
| hydroG urban  | 21.76** (.016)      |
| lagdco        | 11.30 (.33)         |
| dy            | 0.88 (.5531)        |
| dy^2          | 0.85 (.5608)        |
| dhydroG       | 0.32 (.3732)        |
| durban        | 2.158** (.0271)     |

*** and ** indicate significance at the 1% and 5% levels, respectively.

Conclusion and Policy Implications

The present study investigates the impact of economic growth, hydrogenation, and urbanization on CO2 emissions along with testing the EKC hypothesis in Malaysia by taking quarterly data from the period 1965 to 2018. This study applies Quantile Autoregressive Lagged (QARDL) technique by Cho et al. (2015). Further, we also have examined causality in quantiles following Troster (2018) to identify the causal path among the economic growth, hydro generation, and urbanization and CO2 emissions. The outcomes demonstrate that hydropower generation decreases the detrimental effects of CO2 emissions only at higher quantiles. Furthermore, urbanization, in lower to higher quantiles, exhibits negative impacts on CO2 emissions. Likewise, the QARDL coefficients confirm the presence of the Environmental Kuznets Curve hypothesis from median to higher quantiles. Besides, the Granger-causality test confirms the two-way causality between CO2 emissions and hydropower generation in Malaysia’s economy.

Based on the above empirical results, the present study recommends expansionary hydropower energy policies as they will be beneficial to substituting fossil fuel energy and alleviating environmental degradation (Solarin & Ozturk, 2015). Hydropower project costs are very high and unbearable for developing countries. Therefore, international financial institutions in collaboration with developing countries should incentivize the private sector to attract financing for hydropower projects. Results from quantile regression showed an increasing coefficient for hydropower generation, which means the negative impact of hydropower gets stronger while we move from low to higher quantile levels of hydropower. This justifies the importance of hydropower at higher quantile levels. Therefore, the finding calls for more financial allocation from the public sector budget and through the private sector. Since Malaysia is a developing economy, therefore, it is not easy to bear a direct financial burden to boost the hydropower projects. Therefore, we suggest the phase-wise development of power projects without affecting the budget balance of a developing economy like Malaysia. Similarly, the impact of urbanization at higher quantile levels is shown as insignificant, which implies that the Malaysian urbanization level has reached the level of less harmfulness. Therefore, encouraging urbanization to a further level is recommended.

This study has some limitations which can be overcome in future research. The findings of the present study do not

Table 8. Quantile Causality Analysis Results.

| Quantiles | 0.5–0.95 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|-----------|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Y→CO2     | 0.00***  | 0.45 | 0.00*** | 0.00*** | 0.00*** | 0.45 | 0.13 | 0.12 | 0.00*** | 0.00*** | 0.4  |
| hydroG→CO2| 0.00***  | 0.45 | 0.00*** | 0.00*** | 0.00*** | 0.45 | 0.13 | 0.12 | 0.00*** | 0.00*** | 0.4  |
| Co2→Y     | 0.00***  | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.41 | 0.00*** | 0.00*** | 0.00*** | 0.00*** |
| hydroG→Y  | 0.00***  | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.41 | 0.00*** | 0.00*** | 0.00*** | 0.00*** |
| CO2→hydroG| 0.00***  | 0.44 | 0.00*** | 0.00*** | 0.00*** | 0.04** | 0.18 | 0.05** | 0.00*** | 0.00*** | 0.01** |
| Y→hydroG  | 0.00***  | 0.44 | 0.00*** | 0.00*** | 0.00*** | 0.04** | 0.18 | 0.05** | 0.00*** | 0.00*** | 0.01** |
| CO2→urban | 0.00***  | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.36 | 0.05** | 0.00*** | 0.00*** | 0.00*** |
| Y→urban   | 0.00***  | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.36 | 0.05** | 0.00*** | 0.00*** | 0.00*** |

*** and ** indicate significance at the 1% and 5% levels, respectively.
apply to other countries or regions. Therefore, researchers can apply the same model to other developing and developed economies to make the comparison. Future studies can testify to the same model by applying other non-linear models to explore the plausible asymmetries among the series. To this end, Quantile-on-quantile and Wavelet methods could be a good choice. Also, the scholars can extend this study by examining the interaction role of hydropower generation and globalization in the framework of the pollution haven or environmental halo hypothesis. Finally, the recent model can be enriched by including/replacing some other control variables such as exchange rate, oil prices, terrorism, and financial development to obtain more interesting findings.

**Nomenclature**

| Abbreviation | Description                  |
|--------------|------------------------------|
| CO₂          | Carbon emission              |
| HEC          | Hydropower energy consumption|
| RENE         | Renewable electricity        |
| EFP          | Ecological footprint         |
| HYDEC        | Hydroelectric consumption    |
| CWT          | Continuous Wavelet transformation |
| ENG          | Energy consumption           |
| GHG          | Greenhouse gas               |
| hydroG       | Hydropower generation        |
| ARDL         | Autoregressive Distributed Lag Model |
| FMOLS        | Fully Modified Ordinary Least Squares |
| WDI          | World Development Indicators |
| Y            | Economic growth              |
| Y²           | Economic growth square       |
| GENI         | Green innovation             |
| REN          | Renewable energy consumption |
| MSVAGC       | Markov Switching-Vector Autoregressive Granger causality |
| NGS          | Natural gas subsidy          |
| COVID-19     | Coronavirus                  |
| EKC          | Environmental Kuznets Curve |
| Urban        | Urbanization                 |
| VECM         | Vector Error Correction Model|
| QARDL        | Quantile Autoregressive Lagged |
| ASEAN        | Association of Southeast Asian Nations |

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The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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